An Evaluation of Lucerne Varieties for Seed Yield and Strategies to Enhance Seed Production

A report for the Rural Industries Research and Development Corporation

By Dr Ross W Downes

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Foreword

Australian rural industries frequently have an export focus, contributing positively to the national balance of payments. Pasture seed production contributes seed for export as well as seed for pasture establishment in Australia. Lucerne seed makes a significant contribution in these regards. Although lucerne seed production is an established industry, and much of the crop is grown with irrigation, nationally seed yield is variable and below potential.

This project was designed to evaluate varieties currently grown to determine their limitations, and to investigate factors affecting performance. Strategies developed in this project will lead to increased productivity and reliability of lucerne seed production

This publication reports some of the findings, implications and proposals for modified management of lucerne seed crops. It also indicates areas in which plant breeding and further research can be expected to substantially increase production and profitability of lucerne seed production.

This project was funded from industry revenue which is matched by funds provided by the Federal Government.

This report, a new addition to RIRDC's diverse range of over 800 research publications, forms part of our Pasture Seeds R&D program, which aims to facilitate the growth of a profitable and sustainable pasture seeds industry based on a reputation for the reliable supply, domestically and internationally, of a range of pasture seeds.

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Simon Hearn
Managing Director
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About the Author

Dr Ross Downes studied at Queensland University for the B Agr Sc (1st class Honours) and M Agr Sc degrees and Cornell University, NY where he obtained the PhD degree in genetics, plant breeding, physiology and agronomy.

He worked in CSIRO Plant Industry for many years where he rose to Senior Principal Research Scientist, working in the fields of crop adaptation, plant physiology and plant breeding. He has published 80 scientific papers.

Since 1988 he has operated as a consultant, contractor and research director of Innovative Plant Breeders. He has been Principal Investigator in four RIRDC projects.

Contents

Executive Summary

This research program was conducted by Dr Ross Downes, Innovative Plant Breeders,1998-2001, to evaluate lucerne varieties for seed yield and to investigate strategies to enhance seed productivity.

Using the best available agronomic management practices on farms, it was proposed to identify lucerne varieties with the highest seed production. To ensure that this research program was of direct benefit to the lucerne-seed industry, studies were conducted in commercial fields, with supplementary investigations in nurseries and glasshouses.

Findings

Crop establishment and management

Seed yield is determined by the product of two components: number of stems and yield per stem.

- The number of stems in a seed production field is affected by crop establishment, losses due to disease, moisture stress and management.
- Differences in stand or plant population between different fields can have a large effect on variation in yield.
- Yield per stem is determined by the number of pods set which depends on flowers being tripped, and the number of seeds per pod which depend on pollination and fertilisation.
- These components are affected by management, weather, pollinators and varietal characteristics.

Varietal performance

Performance of some varieties is more stable than others under both irrigated and dry land conditions.

Some varieties produce higher yields than others

Varieties are variable and contain a proportion of plants with poor seed yield potential

Trials in seed production districts can assess seed yield potential and longevity of varieties.

Breeding

There is sufficient variation in lucerne varieties for seed yield to be increased substantially by selection and breeding.

With superior varieties, adequate stand and good management, yields of one tonne per hectare with a value of $3000 should be achieved, a three fold increase over current yields and returns.

Pollination

- Observations during the 2000 season revealed no difference in seed yield in crops in locations close to, and remote from hives.
- Bees were present in crops, collecting nectar without tripping the flowers, and were therefore transferring very little pollen between flowers.
- Bees were seen to be actively collecting pollen from couch grass and weeds and not from lucerne.

Many plants in currently available varieties have flowers which trip automatically and their frequency can be increased by selection and breeding.

Rain during the flowering period affects pollination and fertilisation and can reduce yield potential substantially

The risk of rain reducing yield can be minimised by staggering crops to ensure that they pass through the sensitive flowering phase at different times.

Irrigation practices

When overhead irrigation was used there was evidence of reduced numbers of seeds per pod, reflecting lack of fertilisation of ovules.

Seed yield per stem is similar in spring dry land crops , and summer crops which are irrigated four or five times using 600 mm of water.

More efficient water use would save water to allow a three-fold increase in area irrigated.

Spring irrigated seed crops, have the potential to use only 200 mm water.

Implications

Crop establishment and management

Seed yield is determined by the product of number of stems and yield per stem.

Effective crop establishment is essential.

Superior grazing management is needed to avoid plant losses and resowing costs.

Plant diseases such as lucerne yellows cause loss of stand and should be controlled.

Management of both beneficial and destructive insects is important.

Specialist independent crop monitors can provide valuable advice to growers.

Selection of varieties

There is variation in performance of varieties within and between farms.

Plant stand, timing of irrigation, soil characteristics and other management practices have a bearing on varietal performance.

Some varieties were more variable in performance than others and some consistently produced higher yields.

Seed yield and longevity can be assessed in trials.

Breeding

There is sufficient variation in lucerne varieties for seed yield to be increased substantially by selection and breeding.

With superior varieties and good management, yields of one tonne per hectare with a value of $3000 should be achieved, a three fold increase over current yields and returns of $1000/ha.

Growers already achieving 1 tonne/ha can also expect substantial gains.

Pollination

Honey bees as pollinators costs the industry $600,000/year.

The cost effectiveness practice of using honey bees as pollinators is of doubtful value.

Irrigation practices

Seed yield per stem is similar in dry land crops in spring and summer crops which are irrigated four or five times using 600 mm of water.

Spring irrigated seed crops use considerably less water than summer crops

More efficient water use would provide a three-fold increase in area irrigated and an increase in returns of seed produced three-fold to $45 million.

Spring crops avoid seed wasp attack which currently reduces export returns by $5million/year.

Recommendations

Crop establishment and management

Growers should take care in sowing to obtain a dense stand of plants

Rotational grazing should be used to retain stand

Effective treatments for insect and disease attack should be used

Crop monitors should be employed to advise on appropriate management strategies

Disease resistant varieties should be planted to minimise losses and maintain stand

Selection of Varieties

Varieties should be evaluated for seed production as well as for fodder production

For reliable results varieties should be included in seed yield trials for three years and in diverse sites

Trials should be conducted by independent operators

Management of Pollination

Seed growers should evaluate effectiveness of honey bees in tripping flowers

Seed growers should consider benefits of honey bees against cost of $600,000 per year

Potential of leaf-cutter bees to increase yield should be costed

Growers should seek varieties with automatic tripping to remove need for pollinating insects

Breeding New Varieties

Breeders should select varieties for increased seed yield

Development of varieties with high levels of automatic tripping should be undertaken to reduce cost and unreliability of pollinators

Varieties with multiple resistances should be bred to reduce stand loss

Germplasm should be evaluated to reduce weather losses in mature crops awaiting harvest

Evaluation of irrigation practices

Dry land seed crops should be considered to complement irrigated crops

Irrigated spring seed crops should be evaluated to conserve water and reduce seed wasp losses

Water use efficiency in spring and summer seed crops should be examined

Growers should consider having crops flower and mature at different times to spread loss risk

Water stress to stimulate flowering should be evaluated as a management tool

Possible detrimental effects of overhead watering at flowering time should be examined

Introduction

Lucerne is a valuable multi-purpose fodder plant with characteristics which make it well adapted to the variable Australian environment. It is sown on approximately 200000 irrigated hectares for hay production, and alone or in mixtures under dry land conditions where its drought resistance and resilience are highly valued. In recent times it has gained acceptance as a valuable plant to dry soils and lower water-tables in efforts to arrest the spread of dry land salinity.

This report describes a research program conducted by Dr Ross Downes, Innovative Plant Breeders, and supported by RIRDC for three years, to evaluate lucerne varieties for seed yield and to investigate strategies to enhance seed productivity. The project was developed in an effort to investigate the considerable discrepancy between average seed yields and superior production obtained by some experienced seed growers. In addition, an explanation of the variation in seed productivity on an annual basis, even in irrigated crops, was needed.

Figure 1 Lucerne Plants Showing Differences in Pod set

The perception of variation among varieties in yield and reliability was investigated because seed producers have to make long term commitments when sowing fields for seed production. Improved knowledge of factors affecting seed production was also investigated to ensure reliable production, an important factor in gaining and maintaining an increased share of export markets.

It was anticipated that greater understanding of the physiology of the seed production process and identification of deficiencies in varieties would assist breeders improve seed production in varieties being developed for Australian conditions. Walker *et al.* (1996) reported that seed growers thought plant breeders need to place a higher priority, during breeding programs, on selecting plant characters which will increase pollination efficiency and seed yield. However, neither Humphries and Auricht (2001) nor Irwin *et al*. (2001) in extensive reviews, mentioned past or current efforts to select lucerne for high seed yield in Australia. Consequently it was considered that this project could make a valuable contribution if it could evaluate varieties for seed yield and through identification of restraints, propose strategies to enhance seed productivity.

Of the seed produced in Australia about 65% (sometimes as much as 5000 tonnes) is exported, returning up to AUD15 million. If adequate seed yields can be obtained to make seed production more rewarding, there is potential for a significant expansion of seed exports, particularly to the US. Although improved management practices have been identified in New South Wales, in 'Lucerne Seedcheck' (Walker *et al*., 1996), and appropriate practices are used by experienced growers in South Australia, average seed yield is very low, only 250 kg/ha in South Australia and 115 kg/ha in New South Wales. However some growers have obtained yields of more than one tonne/ha, indicating that average yield is significantly below potential.

It is well recognised that an adequate plant stand is essential for good yields of seed. Growers are aware of the need to obtain good establishment at sowing, careful grazing management and adequate disease and pest control to maintain plant populations. However some varieties have a good reputation for consistently high seed yields but others have an inferior and variable performance.

This study was designed to not only evaluate varieties for seed yield but also to determine the key characteristics of the varieties which contribute to their performance. However, as varieties are exposed to a large number of influences, interactions between varieties and management and environmental factors have to be considered. As the seed production process is determined by initiation of flowering, numbers of flowers and duration of flowering, tripping of flowers, pollinators and pollination, fertilisation, pod set and seed development, a detailed examination of the reproductive biology of lucerne was undertaken.

A study of this nature requires that a large number of influences and effects be dissected and analysed to gain a thorough understanding of the issues affecting lucerne production. It is anticipated that interpretation of factors affecting seed production and their synthesis into a new framework will facilitate the development of strategies to enhance seed productivity.

Outcomes and Objectives

An evaluation of currently available lucerne varieties and management practices

An understanding of the characteristics of a lucerne variety with potential for high and stable seed yield

An understanding of the various environmental and management conditions necessary for potential yield to be realised

An analysis of potential economic and environmental consequences of use of modified varieties and management

An indication of additional research and development needed to achieve greater productivity in the lucerne seed industry

Literature Review

Factors affecting lucerne seed production have been actively researched for close to 100 years. As many of the issues debated now are similar to those concerning seed growers and scientists in Australia and in other countries in the past, relevant published information is reviewed here.

Management

Management of lucerne seed crops in South Australia was discussed by Doull (1961). He considered that improved yield of lucerne seed is dependent on three factors, changes in management, better control of insect pests and more efficient pollination. Monitoring of South Australian lucerne seed crops for insect attack was undertaken by Maelzer *et al.* (1981). They noted that lucerne produces an abundance of flowers which allows crops to compensate for insect damage. Although they considered the level of insect attack during their studies was below an economic threshold, De Barro (2001) estimated that the seed wasp alone caused lost export potential of $5million annually.

'Lucerne Seed Check', a management support system addressing a large number of issues was developed in New South Wales (Walker *et al.*, 1996). Seed growers were encouraged to keep notes, improve pest management, fertility and weed control, and pay greater attention to irrigation practices. Rincker *et al*. (1988) investigated appropriate practices contributing to lucerne seed production under irrigated conditions in California. Positive factors included clear warm days with little or no rainfall to promote flowering and activity of pollinating insects, control of detrimental insects, supply of effective pollinators and skilful application of irrigation water. Grandfield (1945) quoted Alter (1920) as stating that lucerne plants require some stress to force seed set. Grandfield observed that the number of flowers setting pods increased as humidity decreased from 90 to 10 percent. He also reported that 27^0C was the optimal temperature for pod setting and that setting decreased above 37^0C.

Engelbert (1932) concluded that before the blooming period there must be sufficient water for vigorous growth of plants, a dry period at flowering to slightly stress plants aids seed set and later, when pods have set, more moisture is required to ensure pod filling. He considered that stripping of flowers is due to failure of fertilisation, and can be caused by lack of moisture, heat stress and hot dry winds. Similar conclusions were reached by Tysdal (1946) who reported poor seed set if fields were irrigated at flowering time through competitive vegetative growth being stimulated and adversely affecting seed set. Favourable results were obtained with light irrigation after flowering. Clarke and Fryer (1930) reported that crop failures had been attributed to unfavourable weather during floral development and rapid vegetative growth during the flowering period due to excessive soil moisture.

Flowering and Tripping

Clarke and Fryer (1930) found that some plants consistently produced a high percentage of sterile pollen while others reliably produced fertile pollen. They quoted Gray (1925) for noting wind as an ineffective agent for tripping flowers and Piper *et al*. (1914) for observing automatic tripping of flowers in bright sunshine in the absence of pollinating insects. Knowles (1943) reported that occasional plants set seed well without insect visitation because of a high degree of automatic tripping. Further, he detected considerable variation in the variety Grimm, in both tripping and pod setting behaviour. Carlson (1946) also demonstrated considerable variation among clones in seed set.

Hadfield and Calder (1936) concluded that lucerne flowers must be tripped to produce seed. Armstrong and White (1935) showed that tripping effected contact between stigma and pollen through rupturing a thin membrane on the stigma. The anatomical structure of the lucerne flower and an explanation of the tripping mechanism were provided by Larkin and Graumann (1954). They identified two forces in tripping: pressure exerted by the sexual column from cells under tension at the juncture of the staminal tube and the keel; and the restraining nature of keel petals that cohere due to interlocking finger-like projections of cutinised tissue on the appressed surfaces of the keel petal. When the force of restraint is overcome, the flower trips. Studies by Kreitner and Sorensen (1985) using electron microscopy revealed that keel petals are locked together by parallel ridges and grooves. They concluded that moisture tension facilitates tripping and speculated that intermeshed cell-wall ridges partially collapse with loss of turgidity and are more easily disengaged by pollinator activity.

Busbice and Wilsie (1966) found the easy-to trip-trait was highly heritable. Knapp and Teuber (1990) observed that flowers were easier to trip when the humidity was low coupled with high soil moisture. They found that under field conditions easy-to-trip plants have 230% as many flowers tripped, and 41% greater seed yield than do hard-to-trip plants. They concluded that ease of tripping should be more easily increased by breeding than by modifying field conditions. Knapp *et al.* (1993) determined that phenotypic recurrent selection is the most efficient breeding method to improve ease of tripping. Knapp and Teuber (1994) selected for increased ease of tripping in lucerne populations with a view to developing types that were easier to trip by honey bees. The outcrossing rate of easy-to-trip populations did not differ from outcrossing rate of hard-to-trip groups indicating that selection for ease of tripping does not increase inbreeding, (Knapp and Teuber 1993). Plants with the ability to trip automatically were observed to set the most seed in the current investigation.

Insects and Pollination

Tysdal (1940) concluded that leaf-cutter bees (*Megachile*) and alkali bees (*Nomia*) were responsible for most of the tripping and pollination of lucerne flowers while honey bees tripped only 1% of flowers visited. Bohart (1957) reported Muller (1873) as the first to note that nectar-collecting honey bees avoid the pollination mechanism in lucerne by inserting their proboscis into the side of the flower. Rincker *et al*. (1988) and Petersen *et al*. (1972) reported that pollen collecting honey bees trip a large proportion of florets visited but nectar collecting bees trip only 2% of florets. Palmer-Jones and Forster (1972) demonstrated that when honey bees were confined in cages in which lucerne was the only pollen source, lucerne pollination was enhanced. However elimination of alternative pollen sources in the field, to increase cross pollination of lucerne was not considered feasible in New Zealand. Although there was increased seed production with increased bee populations of up to 11 hives per hectare in Canada (Pankiw *et al*. 1956), it was concluded that returns did not justify costs. In South Australia in an extensive field experiment no relation was found between lucerne seed yield and bee numbers by Maelzer and Pinnock (1983).

Tysdal (1946) reported honey bees vigorously collecting pollen and tripping lucerne when there were few other pollen sources. Stephen (1955) noted that honey bees are of little importance in lucerne seed production in Manitoba because of the abundance of sources from which pollen can be more readily obtained. To monitor sources of pollen collected by honey bees, Vansell and Todd (1946) examined the types of pollen in traps on bee hives. They found much more lucerne pollen in hives in Utah when fields were surrounded by desert rather than diversified crops. Near Logan, a diversified farming area, no lucerne pollen was detected in hives, bees preferring pollen from Composites, clovers and Brassicas. In one study it was observed that *Megachile* (leaf-cutter bees) were also much more attracted to a weed (*Grindelia*) than to lucerne.

In Alberta, Hobbs and Lilly (1955) observed almost no lucerne pollen collected while bees took pollen from other legumes. In contrast, Hare and Vansell (1946) reported honey bees collected lucerne pollen very actively in the Delta, Utah. In South Australia, red gum (*Eucalyptus camaldulensis*) flowers in December and January and competes strongly with lucerne as a pollen source (Doull 1961). Dwyer and Allman (1933) noted variable reports of the effectiveness of bees in tripping flowers but they were able to increase seed production by caging honey bees on lucerne plants. They concluded that hives of honey bees should be placed near lucerne seed areas.

Kirk and White (1933) described self-tripping flowers and Stevenson and Bolton (1947) evaluated the character in plant breeding, concluding it could be useful if inbreeding could be avoided through use of self-sterile, cross-fertile types. Armstrong and White (1935) observed that environmental conditions, particularly direct sunlight, influenced the expression of the self-tripping character. They reported that in the greenhouse 50% of flowers on 'high pod setting plants' set pods without manipulation while only 5% of flowers on 'low pod setting plants' set seed under these conditions. They concluded that self-tripping is the factor which very largely determines the differential seed-setting capacity of lucerne plants. Lesins *et al.* (1954) recorded 13 to 65 % of flowers tripped automatically in open conditions but automatic tripping was rare in cages. Hely and Zorin (1977) observed substantial differences among varieties in automatic tripping at 25^0C and 40% relative humidity. The findings that honey bees are frequently ineffective in tripping flowers in many of the above papers are in accord with observations in this project.

Efforts to import leaf-cutter bees for evaluation as lucerne pollinators in Australia have been hampered by quarantine restrictions including the need to breed the bees while in quarantine and restraints on their release (Maelzer and Oliver, 1989). Woodward and Maelzer (1990) documented several management problems delaying extensive evaluation of leafcutter bees. However Anderson (Personal Communication, 2001) reported use of different strains of *Megachile* and modified import and quarantine treatment conditions are improving the prospects for use of leaf-cutter bees in Australia.

Fertilisation

Tripping the flower is an essential component of pod set, but the ovules in the pod each require fertilisation by a pollen grain to permit seed production. As cross pollinated species like lucerne exhibit high levels of self incompatibility to minimise self pollination, tripping does not ensure fertilisation. Foreign pollen is required for this. Hadfield and Calder (1936) observed pollen on standards of untripped flowers. They considered pollen may have been dispersed by wind, bees or the explosive tripping process. When greased microscope slides were suspended within a crop in full flower for 24 hours, 5 pollen grains were trapped per cm^2. Hadfield and Calder concluded that wind dispersal of pollen is likely to be important in cross pollination of lucerne in view of the obvious inefficiency of honey bees. Dwyer and Allman (1932) studied the spread of pollen when lucerne flowers were tripped mechanically over dark paper and detected pollen in a circle of 25 cm diameter. They deduced that pollen would be spread further through elevation and wind and considered this in relation to the finding of Waldron (1919) that there was 40% natural cross pollination on prostrate lucerne but only 7% on an adjacent erect form. In contrast, Pankiw and Bolton (1965) obtained very little seed-set when they sprinkled viable pollen on the standard petals of male sterile plants before tripping flowers. Dwyer and Allman (1932) considered that dissemination of pollen through artificial or automatic tripping threw doubt on the then widely accepted view that tripping by insects contributes to cross pollination and that automatic tripping leads to self-pollination.

Burkart (1937) found 84% cross pollination in Argentina, Knowles (1943) reported 94% cross pollination in Canada and Tysdal *et al.* (1942) observed 89% in the US. Bolton (1948) detected 11 to 100% cross-pollination but usually more than 90%. Petersen (1967) and (1968) reported only 50% cross pollination. Kehr (1973) found 50% cross pollination in studies with both leaf-cutter and honey bees. Doull (1961) in South Australia considered that self-pollinated pods held only one or two seeds and that cross-pollinated pods contained up to 12 seeds. Using these criteria he deduced that 12% of racemes were cross-pollinated, 47% were self-pollinated and 41% set no seed. In the absence of markers or progeny tests it is difficult to substantiate Doull's conclusions concerning cross-or self-pollination.

Cooper *et al.* (1937) artificially tripped flowers of high and low seed producing plants and found the two groups produced 2.13 and 0.99 seeds per pod respectively. They attributed differences to lack of fertilisation and embryo abortion. Tysdal (1940) studied the effect of self- and cross-pollination and observed 36 and 69% pod set, and 2.4 and 3.8 seeds per pod respectively. He also noted considerable variation among plants in pod set after self-pollination but not with cross-pollination. Bolton (1948) found that self-pollination resulted in 1.58 seeds per pod compared with 5.54 with cross-pollination. When Pharis and Unrau (1953) tripped flowers mechanically and found self-pollination resulted in 32% of flowers forming pods with 1.7 seeds per pod while cross-pollination achieved 75% pod set and 4.7 seeds per pod. Bolton and Fryer (1937) suggested that an accumulation of genetic factors which contribute to fertility may tend to retain the seed-setting stability of fertile plants even under unfavourable environmental conditions. Spafford (1938) drew attention to problems of cold weather hindering tripping and rain at flowering time adversely affecting fertilisation. Similar observations were made in this study.

Variation and Selection

Dwyer (1931) reported that although lucerne seed does not set well under natural conditions in New South Wales, some individual plants set seed much better than others. He also observed a marked correlation between sparse vegetative development and good seed production on individual plants. He concluded that:

'In those districts in which seed setting in lucerne is in general very poor, there are to be found some individual plants which set seed freely. If these are good fodder types, and if the characters of good seed and fodder production can be fixed by selection in self fertilised lines, there will be good prospects for evolving superior strains or types of lucerne for these districts from locally-raised seed.'

The possibility that variation in seed production might be related to pollen viability was investigated by Sexsmith and Fryer (1943). They observed little variation in viability of pollen from individual plants during the season but noted that plants differed in their pollen viability. Engelbert (1932) considered that some sterile pollen was insignificant in view of the total quantity of pollen produced. Bolton and Fryer (1937) could not find a general correlation between pollen viability and pod-setting although Armstrong and White (1935) considered that pollen sterility influences pod-setting and number of seeds per pod.

Tysdal *et al*. (1942) and Hadfield and Calder (1936) showed that self-fertilisation leads to loss of seed and fodder yield in subsequent generations. Bolton (1948) reported Kirk as finding four generations of inbreeding reduced yield of fodder by 46% and seed by 78%. Kirk (1927) reported that one generation of inbreeding reduced seed yield 40% and two generations by 70% compared with outcrossed plants of the same strain. Viands *et al*. (1988) concluded that self-incompatibility is only partially effective in preventing self-fertilization. Sayers and Murphy (1966) observed a higher level of ovule abortion after self-pollinating clones of low seed producers than of high seed producers.

Forage yield losses of 32, 49 and 47% after 1,2 and 3 generations respectively of self-pollination were observed by various authors cited by Kimbeng and Bingham (1998). The reduced seed and forage yield following inbreeding caused Kirk (1933) and many others subsequently to discount usefulness of inbreeding in lucerne. However Tysdal and Clark (1934) demonstrated that although inbreeding can reduce seed production, with rigid selection increases in seed yield were achieved with inbreeding. Kimbeng and Bingham (1998) improved herbage yield during inbreeding through selection, which increases the frequency of favourable genes and reduces unfavourable alleles.

In Canada, Fryer (1939) developed a selection programme to increase seed-setting in lucerne. This was initiated in response to long term irregularity in seed production and variation within varieties with some plants producing seed well in regions where seed production was poor. He was able to increase seed production and there was no penalty in terms of fodder production in lines producing high seed yield. Heinrichs (1965) quoted Pedersen (1962) as stating that although lucerne breeders profess to have good seed production in mind, few varieties possess superiority in seed production. Walker *et al*. (1996) reported that seed growers thought plant breeders need to place a higher priority, during breeding programs, on selecting plant characters which will increase pollination efficiency and seed yield. However, neither Humphries and Auricht (2001) nor Irwin *et al*. (2001) in extensive reviews, mentioned past or current efforts to select lucerne for high seed yield in Australia. Heinrichs (1965) reported a breeding program to improve seed production and from progeny tests predicted a 30% and a 13% increase in seed yield at two locations.

Huyghe *et al.* (1999) reported a series of experiments to examine the components of seed yield in lucerne. The seed yield was highly correlated with harvest index and seed weight per pod. A study of the genetic variation for components of seed yield between and within 45 varieties showed greater variance within populations than between varieties especially with respect to seed yield per plant. High seed yielding populations and low seed yielding populations exhibited similar levels of variation for seed weight per inflorescence. The available variation suggests considerable opportunities to breed for increased seed production.

Methodology

These studies were conducted in the vicinity of Keith in South Australia and Forbes in New South Wales which are the major centres of lucerne seed production. Studies were conducted in commercial seed production fields managed by experienced Australian seed growers, with supplementary investigations in nurseries and glasshouses.

At the commencement of the project discussions were held with seed companies in South Australia and New South Wales to identify appropriate growers to participate in the project. Individual approaches were made to these growers, and a group of 3 in each area were selected. Throughout the project, growers provided valuable information concerning management practices and their experiences producing lucerne seed.

As these collaborators are all highly skilled growers who take particular care with crop management including pest control, it was anticipated that the effects of some of the factors which can adversely affect production were minimised.

Seed crops were visited and observations taken at regular intervals of about three weeks, during the seed production period from December until March each year. When crops were mature, samples were taken to allow subsequent study of parameters affecting yield. For progeny tests and additional observations, plots were established on a property at Bordertown, South Australia. Research findings and implications were discussed with seed growers individually throughout the project, and presentations were made at district meetings at both Keith and Forbes. (Appendix 1)

The observations made in this project were confined to an examination of performance under current practices in both dry land and irrigated fields. The co-operating seed growers provided high quality management, effective weed and pest control, and the timing of operations such as cutting, flowering, and harvesting were those in common use. Possibilities outside the range considered normal practice were not evaluated. In view of the need for isolation of crops in the process of producing certified seed it was not possible to establish plot trials in which varieties could be compared under identical conditions.

Independent crop monitoring services were employed by seed growers in South Australia to manage pest control. Growers at Forbes used 'Lucerne Seedcheck', a management support system (Walker *et al*., 1996). Crops were most frequently set aside for seed production between mid November and mid December which is much later than the time (equivalent to 20 October) recommended in California (Jones and Pomeroy, 1962).

In general, plants were watered both to ensure that they were not stressed and to fit into a tight rotational watering regime. This did not allow for a period of moisture stress at flowering which has been considered to enhance seed set (eg Engelbert, 1932). Australian seed growers consider that attempting to generate a modest moisture stress is hazardous and difficult to manage because of possible hot and windy conditions at flowering time.

Hives of honey bees were placed in fields at flowering time to aid in ensuring flowers were tripped and cross-pollinated.

In some instances fields held a primary seed crop, and regrowth from the crown also flowered to provide a double crop. Such mixtures tended to lodge, providing difficulties at harvest time in commercial crops. In thin stands, in which plants carrying mature pods were buffeted by winds, many pods were dislodged and were seen in the litter on the soil surface. Excellent seed yields were often observed on prostrate plants which avoided wind-induced losses. Seed crops were drilled in narrow rows, as opposed to the widely spaced rows recommended for high yield in California (Peterson, 1972).

Plants were observed at flowering time to determine the effect of branches on the main stem on the amount of flowering and pod set on the main stem. The flowering process was studied extensively to monitor bee populations and their activity during the day in relation to weather conditions. The extent to which bees tripped flowers was examined and the propensity of flowers to trip automatically was noted. The numbers of flowering racemes were recorded and the intensity of pod set noted.

When crops were mature, either 10 or 25 individual stems were selected at random and collected for detailed examination. On the main stem attributes considered were : height, number of racemes, number of pods set, and weight of pod, and seed. Weight of pods and seeds on branches was also determined, as was total dry matter of the stem and branches.

In the first year of the study, considerable variation in pod set was observed within individual crops so a selection exercise was undertaken to ascertain whether variation was induced by environmental or genetic factors. Pods were collected both from plants setting a large number of pods and from plants which set few pods. They were then threshed to provide sowing seed from both high and low seed setting plants in a number of varieties. Seed was sown in a nursery near Bordertown, South Australia, in which progenies were observed at flowering and during pod set. Random stems were selected at maturity for dissection and detailed examination.

The possibility that a considerable amount of the automatic flower tripping observed might result in self-pollination was investigated. To provide genetic markers, white-flowered plants were selected in various crops and seed was harvested when crops matured. Seed from individual white flowered plants was sown in a nursery and numbers of plants with blue and white flowers were recorded.

In June 2000 a RIRDC Travel Grant made it possible to attend the 37th North American Alfalfa Improvement Conference in Madison Wisconsin, which provided much useful information and enabled the developing of an extensive network of researchers and growers , with whom contact has been maintained. Throughout the project discussions have been held with Emeritus Professor Royce Murphy from Cornell, NY, who have given freely of his time, and provided some very useful insights, particularly in the interpretation of results. (Appendix 3)

Results

Effect of Seasonal Conditions on Seed Yield

Lucerne seed production depends on the number of plants or stems per hectare and on the seed yield per plant. In seed production blocks, plant stand varies both with location and within fields but is relatively stable from year to year. The number of plants establishing per hectare reflect sowing rate, pest attack and conditions after germination. Subsequently, numbers of plants surviving depend on management conditions, disease attack, weed competition and age of plants. Under irrigated conditions the number of plants per hectare is not normally limited by moisture stress and varies between 10 and 25 or more per m^2. The stand in dry land crops tends to be lower because plants are lost due to summer drought. In this case the stand is commonly in the range of 6 to 10 plants per m^2.

Individual plants can produce a large number of shoots or stems, producing a dense crop to utilise available environmental resources of light and water. Plants can also compensate for loss of stand by producing shoots from the crown so that individual plants may possess more than 20 stems. Data shown in Figure 2) indicate a relationship between stems per plant and plant number. The result is frequently a population of 150 to 200 stems per m^2. The relationship between plant stand and number of stems per m^2 is shown in Figure 3. It appears that number of stems per hectare is extremely important in determining seed yield potential, with low stem number severely limiting yield. Conversely, the highest seed yield per hectare observed in the three years of this study was a harvested yield of 1400 kg/ha, in a field in which a very high number (320) of stems per m^2 was recorded. This was also the highest population of stems per m^2 observed. In dry land situations plant population is lower, and compensation by stem numbers frequently leads to 100 or 120 stems per m^2.

In view of the significance of the population of stems per hectare in determining both potential and realised yield, it is important to recognise that thin stands impose ceilings on yield potential. In the crop analyses reported in this study the average weight of seed per stem was 0.53 grams in irrigated crops. In dry land crops the average yield was 0.46 grams per stem. The substantial effect of numbers of stems per hectare is illustrated in the yield projections shown in Table 1. ∗SD is standard deviation about the mean

Table 1. Expected lucerne yield per hectare (kg/ha)

Crop type	Wt seed per stem grams	100 stems per m^2	150 stems per m^2	200 stems per m^2
Irrigated crops	0.78 mean + SD*	780	1170	1560
	0.53 (mean)	530	795	1060
	0.28 mean - SD	280	420	560
Dryland crops	0.67 mean + SD	670	1005	-
	0.46 (mean)	460	690	-
	0.25 mean - SD	250	375	-
Theoretical	1.00	1000	1500	2000

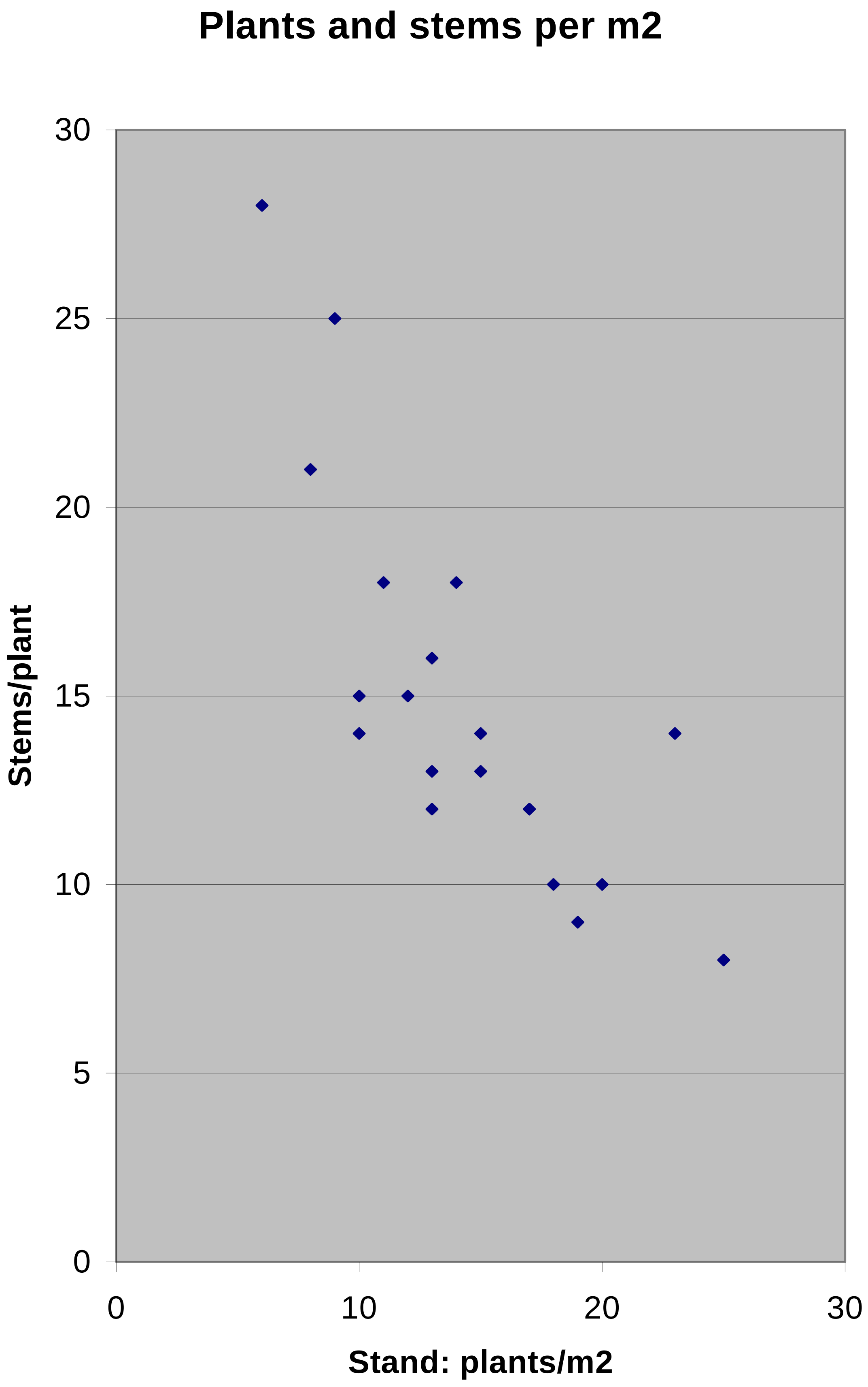


Figure 2 Relationship between plant numbers and stems on plants

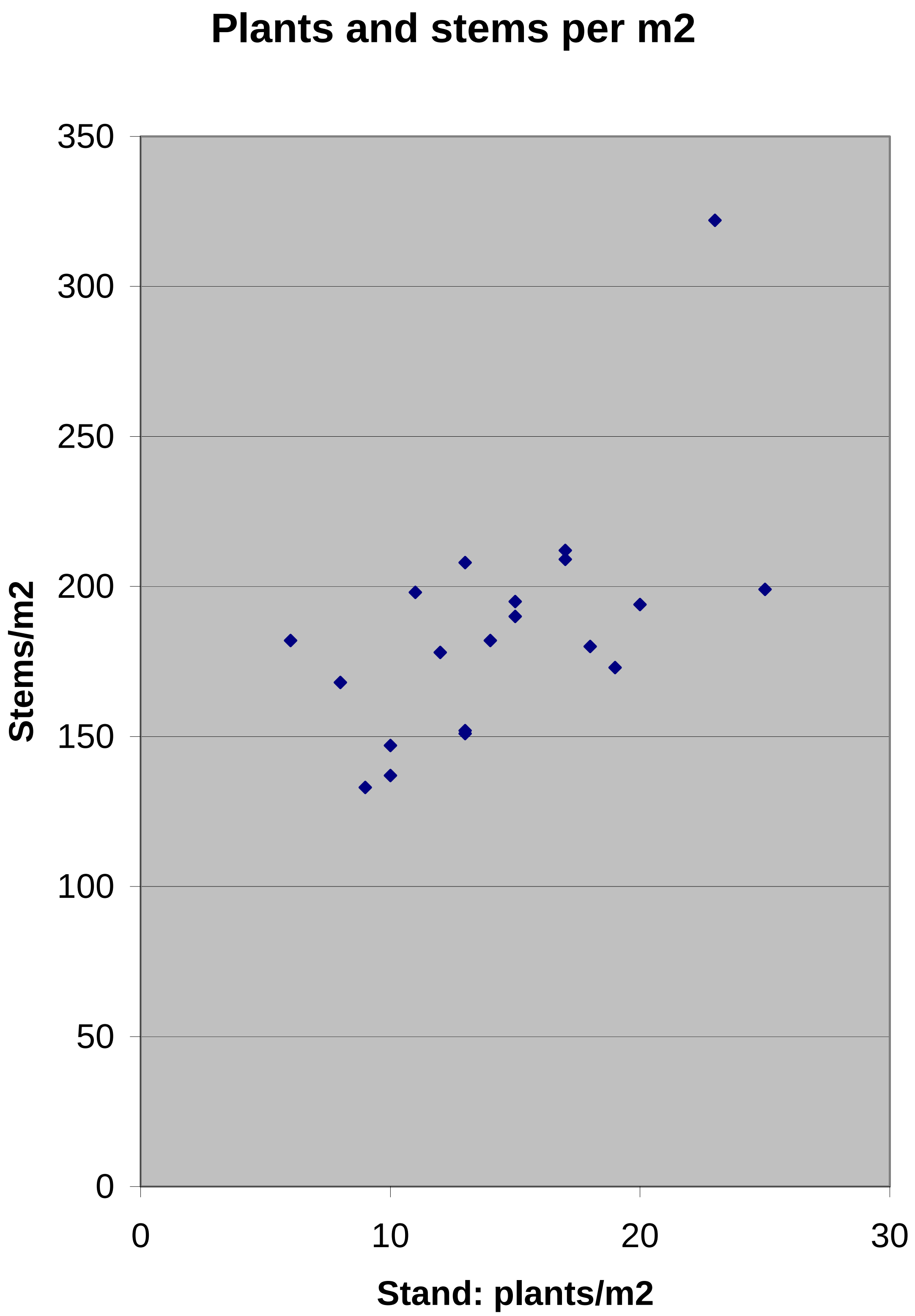


Figure 3 Relationship between stem and plant numbers

Some varieties under some circumstances produced about 1 gram of seed per stem under both irrigated and dry land conditions. Under suitable conditions and 100 and 200 stems per m^2, yields of 1000 kg and 2000 kg/ha can be expected under dry land and irrigated conditions respectively.

Although plant stand and branch number are extremely important in determining the potential and realised seed yield, they reflect standard management techniques rather than varietal characteristics and will not be addressed particularly in this report. Rather, the emphasis will be on seed production per stem. For this purpose stems were randomly selected in fields as the crops reached maturity.

The following data, obtained in a field of ‘Aquarius’ provide an indication of the variation in crops in different years. Stems on an irrigated crop at Keith were sampled and dissected.

Table 2. Seed yield components ‘Aquarius’ 1

Year	1999	2000	2001	LSD
Racemes per main stem	7.7b	12.5a	11.2a	2.2
Number of pods	42.1a	52.1a	20.1b	21.0
Pods per raceme	5.32a	4.29a	1.65b	1.84
Total seed weight	0.45a	0.51a	0.05b	0.23
Seed weight per 100 pods	0.65 a	0.60a	0.18b	0.17
Harvest Index	0.16a	0.19a	0.00b	0.05

These data indicate that seed yield per stem was much greater in 1999 and 2000 than in 2001. Similar yields were realised whether there were 7.7 or 12.5 racemes on the main stem in the first two years. In 1999, although there were fewer racemes produced than in the other two years, number of pods set and seed production was not reduced. This suggests that if there is a good early seed set, the development of further flowers is reduced as the plant concentrates resources into seed production In the third year not only were there fewer pods set, but the seed weight per pod and therefore and weight of seed was reduced. The much poorer performance in this field was not reflected in other crops in 2001. It is likely that this particular field experienced a catastrophic event about flowering time, which reduced pod set, seed weight per pod and consequently the seed yield and harvest index.

In contrast, results from stems on another irrigated crop of ‘Aquarius’ at Keith, sampled in 1999 and 2001, (Table 3) show that the variety performed better in 2001 than in 1999 through higher seed production per stem which reflected higher seed weight per pod. This indicates better pollination in 2001 than in 1999. However in their both Tables 2 and 3 illustrate considerable variation between years in seed production in two fields.

Table 3. Seed yield components Aquarius' 2

Year	1999	2001	LSD
Racemes per main stem	12.1a	11.1a	ns
Number of pods	51.8a	59.8a	ns
Pods per raceme	4.27a	5.02a	ns
Total seed weight	0.35b	0.91a	0.48
Seed weight per 100 pods	0.47b	0.65a	0.13
Harvest Index	0.15a	0.19a	ns

A different response to conditions over three years was shown by 'Aurora'. In this case no significant differences were detected (Table 4). Any possible differences were masked by the variation within this variety.

Table 4. Seed yield components 'Aurora'

Year	1999	2000	2001	LSD
Racemes per main stem	7.8b	11.2a	9.6ab	2.3
Number of pods	37.0a	29.2a	42.3a	ns
Number of pods per raceme	5.00a	2.55a	4.40a	ns
Total seed weight	0.59a	0.26a	0.33a	ns
Seed weight per 100 pods	0.71a	0.48a	0.49a	ns
Harvest Index	0.17a	0.14a	0.13a	ns

In another crop of Aurora, Table 5, seed weight per pod was low in 2000, which suggests poor pollination conditions and possibly a higher level of self-pollination in 2000 than in the other years. Pollen availability may have been limited by wet conditions. In this case also, the high level of variation within the variety made it difficult to identify statistical differences between years. Poor seed set in 2000 depressed the harvest index.

Table 5. Seed yield 'Aurora'

Year	1999	2000	2001	LSD
Racemes per main stem	9.9a	13.8a	11.7a	ns
Number of pods	36.8a	37.2a	28.9a	ns
Pods per raceme	3.81a	2.81a	2.80a	ns
Total seed weight	0.28a	0.18a	0.20a	ns
Seed weight per 100 pods	0.34a	0.20b	0.41a	0.11
Harvest Index	0.10a	0.05b	0.10a	0.04

In an analysis of a crop of Genesis and Keith, Table 6, variation within the variety again made it difficult to establish differences among the yield components in different years. However the low number of pods per raceme in 2000 was reflected in a low harvest index in contrast to 1999 when a high number of pods contributed to a high harvest index. The low number of pods per raceme in 2000 is an indication that adverse conditions prevailed at pollination time. The low harvest index indicates that excess vegetative growth may have competed with reproductive growth during the period of pod setting. A different effect of season was shown by 'Hunter River' (Table 7)

Table 6. Seed yield components 'Genesis'

Year	1999	2000	2001	LSD
Racemes per main stem	11.3a	15.4a	12.7a	ns
Number of pods	60.0a	35.3a	62.3a	ns
Pods per raceme	5.49a	2.32b	4.68a	1.55
Seed weight	0.64a	0.32a	0.48a	ns
Seed weight per 100 pods	0.66a	0.43a	0.50a	ns
Harvest Index	0.20a	0.11b	0.14b	0.05

Table 7 Seed yield components 'Hunter River' 1

Year	1999	2001	LSD
Racemes per main stem	9.3a	7.9a	ns
Number of pods	23.0b	47.3a	18.9
Pods per raceme	2.46b	6.09a	2.13
Total seed weight	0.18b	0.53a	0.17
Seed weight per 100 pods	0.50b	0.76a	0.23
Harvest Index	0.12b	0.23a	0.06

In this irrigated field of 'Hunter River' the number of racemes remained fairly constant over three years, although the number of pods on the main stem and the number of pods per raceme increased from 1999 to 2001. As both the number of racemes and the pod numbers were low in 1999 it appears that pods were aborted after the main stem had lost the ability to produce more flowers to compensate for poor pod set. The exceptional performance of the variety in 2001 reflects the high number of pods set and large number of pods per raceme. In addition the seed weight per pod indicates excellent pollination conditions in 2001. These factors contributed to a much higher harvest index in 2001 than in 1999.

In a further crop of 'Hunter River' results (Table 8) are similar in many respects to those in Table 7 indicating that 2001 was an exceptionally good year for 'Hunter River' seed production. The number of racemes increased in 2000, suggesting that additional racemes developed and flowered to compensate for poor pod set in the earliest flowering racemes. The exceptional seed weight realised in 2001 reflects the total number of pods set and number of pods set per raceme. The high weight of seed per pod in each year indicates a high level of pollen availability to affect fertilisation in this field.

Table 8. Seed yield components 'Hunter River' 2

Year	1999	2000	2001	LSD
Racemes per main stem	8.4b	12.3a	10.4ab	2.7
Number of pods	24.6b	34.2b	74.0a	17.4
Pods per raceme	2.95b	2.79b	7.61a	1.95
Seed weight (T)	0.29b	0.47b	0.92a	0.38
Seed weight per 100 pods	0.61a	0.68a	0.76a	ns
Harvest Index	0.18a	0.15a	0.22a	ns

Table 9 demonstrates variation in the performance of 'Salado'. As the number of racemes was low in 1999 it appears that good early pod set was achieved. In contrast, plants continued to produce additional racemes in 2000, presumably to compensate for poor pod set per raceme and low seed weight per pod. These observations probably reflect poor pollination conditions in 2000. High levels of vegetative production to produce additional racemes coupled with poor seed production contributed to the poor harvest index in 2000. Despite the additional vegetative development and low harvest index in 2000, the total seed weight was comparable in the three years.

Table 9. Seed yield components 'Salado'

Year	1999	2000	2001	LSD
Racemes per main stem	7.3b	18.3a	14.5a	4.1
Number of pods	34.8a	44.4a	55.0a	ns
Pods per raceme	4.77a	2.48b	4.16a	1.55
Seed weight (T)	0.36a	0.39a	0.49a	ns
Seed weight per 100 pods	0.58a	0.41b	0.59a	0.14
Harvest Index	0.17a	0.08b	0.14a	0.04

Stems on an irrigated crop of 'Siriver' at Keith were sampled over three years (Table 10). In this variety there was no statistical difference among years in yield components. Despite the relatively low number of racemes there was high level of pod set and large number of pods per raceme. This variety in this field exhibited a constant performance over the three years.

Table 10. Seed yield components 'Siriver'1

Year	1999	2000	2001	LSD
Racemes per main stem	9.1a	10.3a	8.5a	ns
Number of pods	58.2a	79.5a	57.6a	ns
Pods per raceme	6.16a	7.75a	6.46a	ns
Total seed weight	1.05a	0.61a	0.58a	ns
Seed weight per 100 pods	0.71a	0.56a	0.71a	ns
Harvest Index	0.19a	0.15a	0.17a	ns

Similar observations (Table 11), indicate that the performance of 'Siriver' over 1999 and 2001 was stable with rapid pod set reflected in the low raceme number. High seed weight and high seed weight per pod resulted in a high harvest index.

Table 11. Seed yield components 'Siriver' 2

Year	1999	2001	LSD
Racemes per main stem	9.1a	11.4a	ns
Number of pods	46.0a	39.9a	ns
Pods per raceme	4.94a	4.21a	ns
Total seed weight	1.01a	0.82a	ns
Seed weight per 100 pods	0.97a	0.83a	ns
Harvest Index	0.26a	0.21a	ns

The crop of 'Siriver' shown in Table 12, continued to grow in 2000, and produce additional racemes compared with 1999 indicating that initial pod set was low. This led to more pods being set so that the number of pods per raceme did not differ significantly between the two years. The total seed weight was greater in 2000 than in 1999.

Table 12. Seed yield components 'Siriver' 3

Year	1999	2000	LSD
Racemes per main stem	8.0b	13.3a	3.2
Number of pods	25.5b	46.3a	19.8
Pods per raceme	3.22a	3.62a	ns
Total seed weight	0.52b	0.79a	0.25
Seed weight per 100 pods	0.67a	0.56a	ns
Harvest Index	0.14a	0.19a	ns

In 'Sirosal', (Table 13) it appears that additional racemes were produced in 2000 and 2001 to compensate for a modest pod set. The data also indicate a superior seed set per pod in 1999. This contributed to a higher harvest index in 1999 than in subsequent years.

Table 13. Seed yield components 'Sirosal'

Year	1999	2000	2001	LSD
Racemes per main stem	7.4b	13.0a	13.8a	2.4
Number of pods	47.2a	69.3a	64.8a	ns
Pods per raceme	6.93a	5.22a	4.73a	ns
Seed weight (T)	0.81a	0.84a	0.62a	ns
Seed weight per 100 pods	0.75a	0.42b	0.56b	0.18
Harvest Index	0.23a	0.17b	0.12c	0.03

The variety L69, Table 14, exhibited a stable performance. In this respect its performance was similar to that of 'Siriver' (see Table 10). The high number of pods per raceme and a high seed weight per pod are indicators of a high yield . These factors contributed to high seed yield and harvest index.

Table 14. Seed yield components 'Pioneer L69'1

Year	1999	2000	2001	LSD
Racemes per main stem	8.5a	10.2a	10.8a	ns
Number of pods	44.3a	60.8a	72.6a	ns
Pods per raceme	5.14a	5.83a	6.80a	ns
Seed weight (T)	0.84a	0.83a	1.10a	ns
Seed weight per 100 pods	0.89a	0.80a	1.00a	ns
Harvest Index	0.23a	0.23a	0.26a	ns

Another crop of ‘L69’ (Table 15) also exhibited stability in performance over the sampling period but the performance of this crop was inferior to that reported in Table 14.

Table 15. Seed yield components ‘Pioneer L69’ 2

Year	1999	2000	LSD
Racemes per main stem	8.2b	11.8a	3.5
Number of pods	29.9a	43.4a	ns
Pods per raceme	3.61a	4.08a	ns
Total seed weight	0.25a	0.46a	ns
Seed weight per 100 pods	0.60a	0.67a	ns
Harvest Index	0.17a	0.19a	ns

The performance of ‘Trifecta’ was also constant over three years (Table 16). There was a tendency for the variety to continue to produce new racemes to counter a modest pod set in 2000. Overall the variety produced high seed yield and a high harvest index. The performance of this variety was similar to that of ‘Siriver’ and ‘Pioneer L69’.

Table 16. Seed yield components ‘Trifecta’ 1

Year	1999	2000	2001	LSD
Racemes per main stem	10.9a	13.7a	13.2a	ns
Number of pods	55.4a	42.9a	57.0a	ns
Number of pods per raceme	5.26a	3.51a	4.38a	ns
Total seed weight	0.89a	0.77a	0.99a	ns
Seed weight per 100 pods	0.87a	0.67a	0.79a	ns
Harvest Index	0.26a	0.22a	0.21a	ns

In contrast to the data in Table 16, in another crop of ‘Trifecta’, Table 17, the number of pods set per raceme and per stem was greater in 2001 than in 2000. The seed weight per pod was much lower in 2000 suggesting poor pollination conditions. This contributed to the low harvest index in 2000. In view of the data in Table 16 it appears that the depression of yield components in 2000 reflects management or soil problems depressing yield in 2000.

Table 17. Seed yield components 'Trifecta' 2

Year	2000	2001	LSD
Racemes per main stem	12.4a	11.8a	ns
Number of pods	36.2b	64.3a	26.5
Pods per raceme	3.05b	5.58a	1.75
Total seed weight	0.49b	0.96a	0.46
Seed weight per 100 pods	0.33b	0.66a	0.22
Harvest Index	0.11b	0.18a	0.07

The variety 'Flairdale', Table 18, performed poorly in 2000 through poor pod set per raceme and per plant. The low seed weight per pod also suggests that pollen availability was lower than in the other two years. Poor pod and seed set in 2000 depressed the value of the harvest index.

Table 18. Seed yield components 'Flairdale'

Year	1999	2000	2001	LSD
Racemes per main stem	7.3a	11.4a	10.1a	ns
Number of pods	44.5a	20.4b	42.6a	16.7
Pods per raceme	6.58a	1.63c	4.74b	1.69
Seed weight (T)	0.41a	0.24a	0.38a	ns
Seed weight per 100 pods	0.69a	0.46b	0.77a	0.21
Harvest Index	0.21a	0.10b	0.20a	0.06

At Forbes 'Aurora' (Table 19) produced more racemes per stem in 2000 compared with the other years presumably to compensate for poor initial pod set. The data suggest that plants were able to compensate for this as other yield components were not significantly different among the three years. The performance of this variety was relatively stable over the three seasons.

Table 19. Seed yield components 'Aurora'

Year	1999	2000	2001	LSD
Racemes per main stem	8.7b	13.6a	9.6b	3.1
Number of pods	47.0a	60.8a	57.9a	ns
Pods per raceme	5.38a	5.06a	5.93a	ns
Seed weight (T)	0.34a	0.34a	0.40a	ns
Seed weight per 100 pods	0.51a	0.34a	0.43a	ns
Harvest Index	0.16a	0.14a	0.16a	ns

‘Genesis’, planted at Forbes, (Table 20) produced a comparable number of racemes per stem in the three years but the number of pods set and the number of pods per raceme were much higher in 2001 than in the other years. However in 1999 seed production on branches compensated for poor pod set on the main stem. In 2000 the total seed weight was very low as was the weight of seed per pod, and the harvest index. Not only was the pod set poor but the seed weight per pod indicates low pollen availability for fertilisation.

Table 20. Seed yield components ‘Genesis’ 1

Year	1999	2000	2001	LSD
Racemes per main stem	12.9a	12.1a	12.3a	ns
Number of pods	43.1b	27.1b	75.3a	30.3
Pods per raceme	3.52b	2.58b	6.36a	2.42
Seed weight (T)	0.62a	0.12b	0.69a	0.40
Seed weight per 100 pods	0.73a	0.16b	0.61a	0.22
Harvest Index	0.20a	0.04b	0.21a	0.08

In another field at Forbes different results were obtained in an irrigated crop of ‘Genesis’ sampled over three years and results are summarised in Table 21.

In this field ‘Genesis’ produced more racemes in 2000 than in the other years but there were no statistical differences in total number of pods, number of pods per raceme or total seed weight due to considerable variation in the populations. However there was a greater seed weight per pod and harvest index in 1999.

Table 21. Seed yield components ‘Genesis’2

Year	1999	2000	2001	LSD
Racemes per main stem	9.6b	15.6a	10.9b	4.0
Number of pods	50.2a	62.5a	44.0a	ns
Pods per raceme	5.59a	4.16a	4.09a	ns
Total seed weight	0.86a	0.37a	0.47a	ns
Seed weight per 100 pods	0.65a	0.31b	0.39b	0.15
Harvest Index	0.21a	0.10b	0.13b	0.05

Stems on another irrigated crop of ‘Genesis’ at Forbes were sampled over three years and results are summarised in Table 22. Although there was no significant difference in numbers of pods or number of pods per raceme, there was more seed set in 1999 through seed production on branches. As shown in Table 21, the seed weight per pod was higher in 1999 than subsequently.

Table 22 Seed yield components of 'Genesis' 3

Year	1999	2000	2001	LSD
Racemes per main stem	12.6a	13.7a	13.8a	ns
Number of pods	62.2a	67.9a	43.2a	ns
Pods per raceme	4.65a	4.61a	3.69a	ns
Total seed weight	0.80a	0.31b	0.37b	0.34
Seed weight per 100 pods	0.81a	0.33b	0.46b	0.16
Harvest Index	0.21a	0.10b	0.13b	0.06

Similar results were obtained in another irrigated crop of 'Genesis' at Forbes which was sampled over two years, Table 23. This site was monitored for two years and yield was much lower in 2000 than in 1999. There was no significant difference between years in racemes and pods on the main stem or pods per raceme but the total seed weight with a major contribution from branches was greater in 1999. In 1999 the weight of seed per pod was much higher, indicating better pollination and/or fertilisation conditions than in 2000. The low seed weight contributed to the harvest index being extremely low in 2000.

Table 23. Seed yield components of 'Genesis' 4

Year	1999	2000	LSD
Racemes per main stem	11.6a	11.9a	ns
Number of pods	43.8a	37.1a	ns
Pods per raceme	4.06a	3.27a	ns
Total seed weight	0.55a	0.11b	0.23
Seed weight per 100 pods	0.57a	0.22b	0.12
Harvest Index	0.18a	0.05b	0.04

Stems on a dry land crop of 'Siriver' at Keith were sampled over three years (Table 24) . Seed weight per 100 pods was greatest in 1999 and 2000, reflecting better pollination or fertilisation conditions. Otherwise these dry land crops did not vary over the three years.

Table 24. Seed yield components 'Siriver'

Year	1999	2000	2001	LSD
Seed weight (T)	0.84a	0.50a	0.44a	ns
Seed weight per 100 pods	0.80a	0.87a	0.55b	0.23
Harvest Index	0.26a	0.20a	0.19a	ns

Stems on a dryland crop of ‘Hunter River’ at Keith were sampled over three years (Table 25). There was no variation detected in the components of yield of dry land ‘Hunter River over three years indicating these dry land crops were exposed to similar conditions each year.

Table 25. Seed yield components of ‘Hunter River’

Year	1999	2000	2001	LSD
Total seed weight	0.48a	0.67a	0.49a	ns
Seed weight per 100 pods	0.80a	0.67a	0.84a	ns
Harvest Index	0.17a	0.26a	0.19a	ns

Stems on a dry land crop of ‘Trifecta’ at Keith were sampled during 1999 and 2000, Table 26. This crop of ‘Trifecta’ was stable in performance in the two years it was observed.

Table 26. Seed yield components of dry land ‘Trifecta’

Year	1999	2000	LSD
Total seed weight	0.35a	0.23a	ns
Seed weight per 100 pods	0.66a	0.76a	ns
Harvest Index	0.18a	0.17a	ns

Stems on a dry land crop of ‘Genesis’ at Keith were sampled over three years ,Table 27. The performance of this field of ‘Genesis’ varied considerably from a high total seed weight in 1999, to a low total seed weight in 2000. The seed weight per 100 pods was also low in 2000 and this contributed to a low harvest index that year. It appears that yield of this variety is less stable under dry land conditions than is yield of ‘Siriver’, ‘Hunter River’ and ‘Trifecta’. (Tables 24, 25 and 26).

Table 27. Seed yield components of ‘Genesis’

Year	1999	2000	2001	LSD
Total seed weight	0.66a	0.17b	0.38ab	0.34
Seed weight per 100 pods	0.58ab	0.41b	0.81a	0.31
Harvest Index	0.17a	0.08b	0.21a	0.08

In any year it is difficult to compare the performance of one variety in different fields, or to compare varieties in different fields because of different management and conditions. However if comparisons are made over a period of years pronounced effects of seasonal conditions on yield parameters can be demonstrated. Data for weight of seed from 100 pods were plotted against yield of seed harvested in Figure 3. This shows the relationships in four fields over three years. In one year at Forbes cool wet conditions did not greatly affect pod set. This indicates that flowers were tripped but the fertilisation process was disrupted so that very few ovules per pod developed into seeds. This demonstrates that seasonal conditions can override varietal and management effects. In the three years the average yield of seed harvested was 604, 131 and 478 kg/ha. This variation was far greater than differences among the varieties as indicated by standard deviations of 195, 60 and 66 kg/ha for the three years.

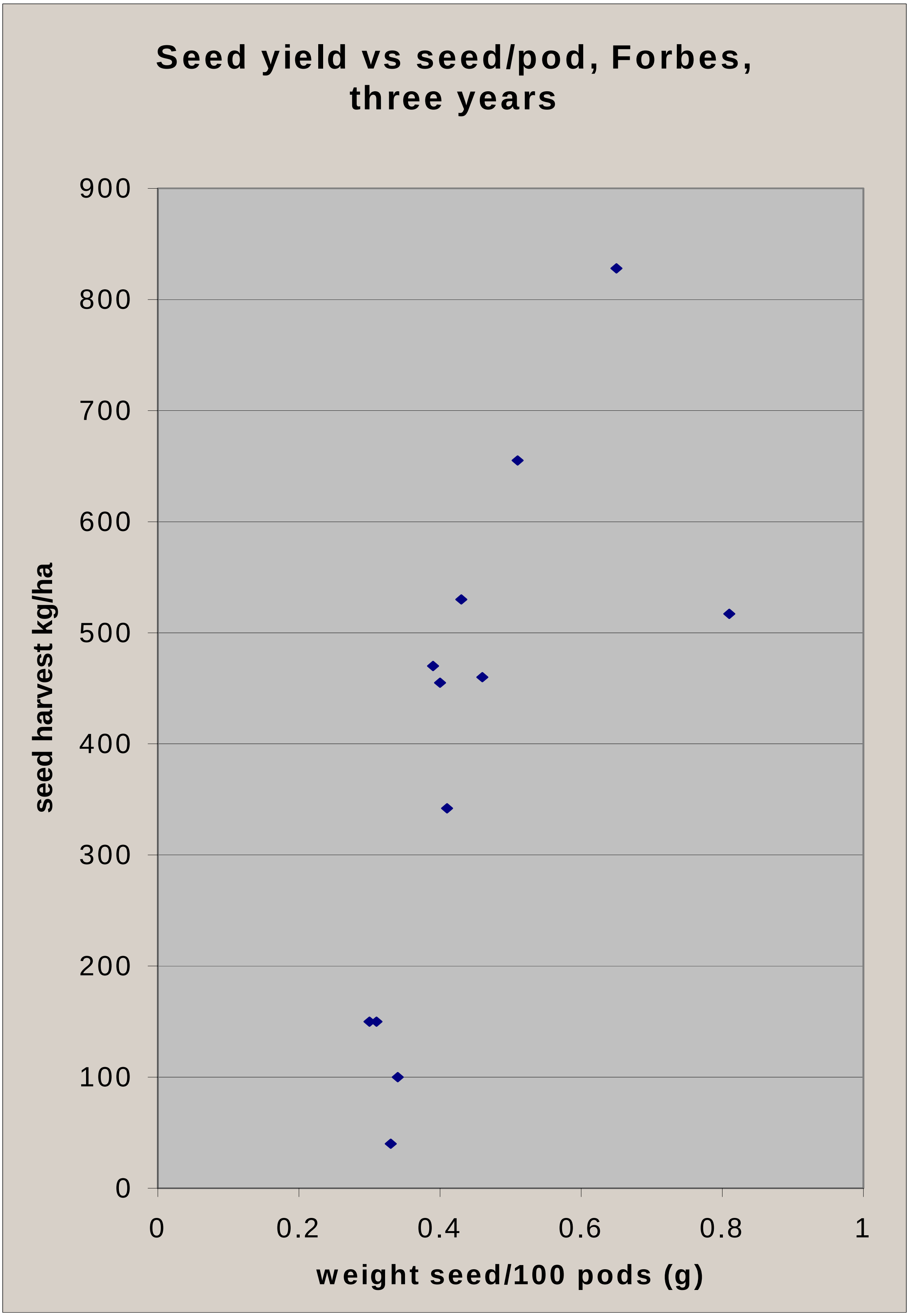


Figure 4 Seed yield vs Weight of seed/pod at Forbes, over 3 years

Effect of Management and Location on Seed Yield

Although performance of lucerne varieties may change from year to year with changing seasonal conditions, performance is affected by irrigation timing, flowering time and soil within and between farms. The extent of such effects is shown in the following data.

Stems on dry land crops of 'Aurora' at Keith were sampled over three years, Table 28. The data indicate that effects due to seasons were more significant than differences due to local effects. For example performance of the variety was superior at both sites in 2001 than in 1999 with total seed weight, seed weight per 100 pods and harvest index all lower in 1999. In one field the harvest index was lower than in the other in 1999. In 2000 the seed weight per 100 pods was higher in one field than in the other. This suggests conditions favoured pollen production, pollination or fertilisation more in one field than in the other.

Table 28. Seed yield components Aurora'

Grower	1	1	1	2	2	2	
Year	1999	2000	2001	1999	2000	2001	LSD
Seed weight (T)	0.11b	0.39a	0.44a	0.28ab	0.25ab	0.48a	0.25
Seed weight per 100 pods	0.28b	0.70a	0.70a	0.48b	0.47b	0.80a	0.26
Harvest Index	0.05c	0.18ab	0.16ab	0.13b	0.13b	0.21a	0.07

Stems on irrigated and semi-dryland crops of 'Siriver' were sampled on two farms at Keith in 1999.The results, Table 29, demonstrated that in 'Siriver' at Keith, one fully irrigated crop did not differ from a dryland crop on the same farm in any of the seed yield components. At the other site, seed yield was enhanced by full irrigation, as was the seed weight of 100 pods and the harvest index. In comparing the two crops with limited irrigation, on one farm flowering stopped abruptly and fewer pods were set on the stem and per raceme than on the other farm. This was reflected in marked differences in total seed weight and harvest index. There were considerable differences between the two irrigated crops. They differed in number of racemes produced and number of pods set. However in the field in which plants produced fewer pods per stem plants compensated by producing greater seed weight per pod reflecting better pollination and fertilisation. These results indicate the significant differences between fields which particularly affected pollination.

Table 29. Seed yield components 'Siriver' 1999

	Site 1	Site 1	Site 2	Site 2	
Treatment	One Irrigation	Fully Irrigated	One Irrigation	Fully Irrigated	LSD
Racemes per main stem	11.8ab	13.2a	8.0c	9.1bc	3.4
Number of pods	70.8a	74.1a	25.5b	46.0b	25.6
Pods per raceme	6.14a	5.91a	3.22b	4.94ab	2.17
Seed weight (T)	1.03a	0.68ab	0.25b	1.01a	0.52
Seed weight per 100 pods	0.74ab	0.55b	0.67b	0.97a	0.23
Harvest Index	0.21ab	0.17bc	0.14c	0.26a	0.06

In a comparison between a dryland crop, a crop with one irrigation and a completely irrigated crop, fields of 'Hunter River' were monitored at Keith in 1999 (Table 30). When three levels of water supply were provided to crops of 'Hunter River' in 1999 there were no statistical differences in racemes produced or numbers of pods. Although there were fewer pods per raceme under dry conditions, there was no statistical difference between treatments in total seed per stem, seed weight of 100 pods or harvest index. The dry land crop was grown on residual soil water from the winter and spring and was ready for harvest in January while the two irrigated crops were mature in March. Consequently the constant value of total seed weight and pod weight indicates that these factors were not much affected by time of flowering.

Table 30. Seed yield components of 'Hunter River'

Treatment	dry	one irrigation	irrigated	LSD
Racemes per main stem	8.7a	7.4a	8.7a	ns
Number of pods	23.4a	33.1a	47.5a	ns
Pods per raceme	2.57b	4.58a	5.29a	2.01
Total seed weight	0.48a	0.32a	0.54a	ns
Seed weight per 100 pods	0.80a	0.60a	0.76a	ns
Harvest Index	0.17a	0.19a	0.24a	ns

Stems were collected from an irrigated and a dry land crop of 'Aurora' at Forbes in 1999 (Table 31). There were no statistical differences between dry land and irrigated plants in parameters affecting seed yield. This illustrates the fact that yield differences between dry land and irrigated lucerne seed crops can be primarily determined by number of stems per hectare rather than by seed production on the individual stems.

Table 31. Seed yield components of ' Aurora'

Treatment	**Irrigated**	Dryland	LSD
Racemes per main stem	9.9a	6.4a	ns
Number of pods	36.8a	31.1a	ns
Pods per raceme	3.81a	4.20a	ns
Total seed weight	0.28a	0.43a	ns
Seed weight per 100 pods	0.34a	0.42a	ns
Harvest Index	0.10a	0.15a	ns

Performance of 'Aurora' (Table 32) grown at one site was constant over the two years but in the other there were more racemes in 2001 and fewer pods per raceme. In 1999 there was compensation for fewer racemes per main stem at one site by increased number of pods per raceme in contrast to the other site. In both years the seed weight per 100 pods was similar indicating comparable pollination conditions, and there was no significant difference between sites.

Table 32. Seed yield components of 'Aurora'

	Site 1	Site 1	Site 2	Site 2	
Treatment	1999	2001	1999	2001	LSD
Racemes per main stem	11.7a	9.6ab	7.8b	11.1a	2.8
Number of pods	46.2a	42.3a	57.0a	38.8a	ns
Pods per raceme	3.97b	4.40b	7.83a	3.62b	2.6
Total seed weight	0.53a	0.33a	0.46a	0.35a	ns
Seed weight per 100 pods	0.51a	0.49a	0.65a	0.63a	ns
Harvest Index	00.16a	0.13a	0.23a	0.17a	ns

Table 33, a comparison of the effect of overhead and flood irrigation on crops at Keith in 2001, shows no difference in the two types of irrigation except in seed weight per 100 pods and harvest index. The lower seed weight per pod may reflect the adverse effect of overhead irrigation during pollination and fertilisation.

Table 33. Seed yield components of crops with overhead and flood irrigation

Year	Overhead (pivot)	Flood	LSD
Racemes per main stem	10.4a	11.4a	ns
Number of pods	48.9a	39.9a	ns
Pods per raceme	4.59a	4.21a	ns
Total seed weight	0.86a	0.82a	ns
Seed weight per 100 pods	0.51b	0.83a	0.32
Harvest Index	0.13b	0.21a	0.07

To provide another comparison between flood and overhead irrigation systems at Keith, yield components were measured on stems, Table 34. There were no significant differences between flood and overhead irrigation treatments in this case except for number of racemes on the main stem.

Table 34. Seed yield components of crops with flood and overhead irrigation.

Treatment	Flood	Overhead	LSD
Racemes per main stem	12.9a	9.6b	2.3
Number of pods	43.3a	35.8a	ns
Pods per raceme	3.63a	4.32a	ns
Total seed weight	0.53a	0.35a	ns
Seed weight per 100 pods	0.65a	0.64a	ns
Harvest Index	0.14a	0.17a	ns

In Table 35 Stems on irrigated crops of ‘Genesis’ in fields at Forbes and Keith were sampled over three years. The performance of the variety was similar in both locations with higher pod weights and harvest index in 1999 than in other years. In both Forbes and Keith the seed weight per 100 pods was much lower in 2000 than in 1999 indicating poor pollination conditions in 2000. This contributed to the harvest index being lower in 2000 than in 1999.

Table 35. Seed yield components of ‘Genesis’

	Forbes	Forbes	Forbes	Keith	Keith	Keith	
Year	1999	2000	2001	1999	2000	2001	LSD
Total seed weight	0.86a	0.37a	0.47a	0.64a	0.32a	0.48a	ns
Seed weight per 100 pods	0.65a	0.31c	0.39bc	0.66a	0.43bc	0.50ab	0.18
Harvest Index	0.21a	0.10b	0.13b	0.20a	0.11b	0.14b	0.05

Stems on two dry land crops of ‘Aurora’ at Keith were sampled over three years and results are summarised in Table 36. This variety performed poorly at one site in 1999 through low seed weight. The weight of seed per pod was low indicating poor fertilisation. The harvest index was low in 1999 at both sites. Performance at both sites was better in 2001 than in the other years.

Table 36 Seed yield components of ‘Aurora’

Field	1	1	1	2	2	2	
Year	1999	2000	2001	1999	2000	2001	LSD
Total seed weight	0.11b	0.39ab	0.44ab	0.28ab	0.25ab	0.48a	0.25
Weight per 100 pods	0.28b	0.70a	0.70a	0.48b	0.47b	0.80a	0.26
Harvest Index	0.05c	0.18ab	0.16ab	0.13b	0.13b	0.21a	0.07

Performance of Varieties in Seed Production

Two varieties were compared when irrigated by overhead pivots at Keith in 2000 and 2001. Results are summarised in Table 37. The varieties differed in seed weight per pod possibly in response to different irrigation treatment during flowering. This affected total seed weight.

Table 37. Seed yield components of two varieties

Variety	A	B	LSD
Racemes per main stem	10.7a	11.3a	ns
Number of pods	31.5a	33.8a	ns
Pods per raceme	3.18	3.20a	ns
Total seed weight	0.31b	0.58a	0.27
Seed weight per 100 pods	0.62b	0.82a	0.16
Harvest Index	0.15a	0.18a	ns

Stems on three varieties grown as dry land seed crops in 1999 at Keith were analysed (Table 38). There was little difference in the yield parameters of the three varieties. All achieved good pod set and excellent seed weight per pod indicating good conditions for pollen transfer at flowering time.

Table 38. Seed yield components of three varieties grown without irrigation

Variety	1	2	3	LSD
Racemes per main stem	10.1a	7.9a	8.8a	ns
Number of pods	38.5a	39.3a	25.2a	ns
Pods per raceme	3.78a	5.25a	3.06a	ns
Total seed weight	1.02a	0.43a	0.45a	ns
Seed weight per 100 pods	0.90ab	0.70b	1.00a	0.21
Harvest Index	0.18a	0.14a	0.17a	ns

Stems on another three varieties grown as dry land seed crops in 1999 at Keith were sampled and analysed (Table 39). There was little difference in the yield parameters of these varieties. All achieved good pod set and excellent seed weight per pod indicating favourable conditions at flowering.

Table 39. Seed yield components three dryland varieties

Varieties	4	5	6	LSD
Number of pods	47.1a	40.0a	51.0a	ns
Pods per raceme	4.35a	4.41a	5.29a	ns
Total seed weight	0.81a	0.41a	0.68a	ns
Seed weight per 100 pods	0.77ab	0.65b	0.99a	0.27
Harvest Index	0.20a	0.20a	0.20a	ns

Stems on crops of another two varieties, ‘Genesis’ and ‘Aurora’, grown in 1999 at Keith were analysed and results are summarised in Table 40. As with the varieties above, there was little difference in the yield parameters of these varieties grown under dry land conditions. Both achieved good pod set.

Table 40. Seed yield components of dryland ‘Genesis’ and ‘Aurora’

Varieties	Genesis	Aurora	LSD
Number of pods	40.7a	39.2a	ns
Pods per raceme	4.10a	4.90a	ns
Total seed weight	0.69a	0.56a	ns
Seed weight per 100 pods	0.78a	0.56a	ns
Harvest Index	0.15a	0.15a	ns

Although soils and management may vary from field to field some sources of variation are removed if varieties are compared for three years on one property. ‘Aurora’ and ‘Genesis’ were compared at Forbes, Table 41. The only appreciable difference in yield parameters was in seed weight. Seed weight per stem advantage of ‘Genesis’ appears to be due to superior seed production on branches and increased dry matter production because the harvest index was identical in the two varieties.

Table 41. Seed yield components of irrigated ‘Genesis’ and ‘Aurora’

Varieties	Genesis	Aurora	LSD
Racemes per main stem	12.0	10.6	ns
Number of pods	52.2	55.2	ns
Pods per raceme	4.6	5.5	ns
Total seed weight	0.57a	0.36b	0.19
Seed weight per 100 pods	0.45	0.43	ns
Harvest Index	0.15	0.15	ns

‘Aquarius’ and ‘Salado’ were grown on one property at Keith for three years, Table 42. There were no differences except in racemes per stem which indicates that ‘Salado’ flowered for a longer period.

Table 42. Seed yield components of irrigated ‘Aquarius’ and ‘Salado’

Varieties	Aquarius	Salado	LSD
Racemes per main stem	10.5b	13.4a	1.8
Number of pods	38.1	44.7	ns
Pods per raceme	3.75	3.80	ns
Total seed weight	0.33	0.42	ns
Seed weight per 100 pods	0.48	0.53	ns
Harvest Index	0.13	0.13	ns

When ‘Aquarius’ was compared with ‘Siriver’ on one farm at Keith the data shown in table 43 were recorded. Over three years ‘Siriver’ was more productive than ’Aquarius’ in all of the yield components except number of racemes on the main stem. The number of pods set on the main stem and the weight of seed per pod, indications of higher levels of tripping, and better pollination and fertilisation were higher in ‘Siriver’ and these factors contributed to a superior harvest index.

Table 43. Seed yield components of irrigated ‘Aquarius’ and ‘Siriver’

Varieties	Siriver	Aquarius	LSD
Racemes per main stem	9.3	10.5	ns
Number of pods	65.1a	38.1b	20.3
Pods per raceme	6.8a	3.8b	1.2
Total seed weight	0.75a	0.33b	0.25
Seed weight per 100 pods	0.66a	0.48b	0.11
Harvest Index	0.17a	0.13b	0.03

Pollination and Fertilisation

Bees Distance from Hives

Experiments were conducted in three varieties to determine if distance from hives affected seed yield. Samples were taken in three irrigated crops at Keith. In 'Aquarius' (Table 44) samples were taken 10 metres and 420 m from hives. There was no significant difference between locations in the characters: pod number, seed number, number of seeds /pod, total seed weight, weight of seeds per 100 pods and harvest index. Similarly, in 'Hunter River' and 'Trifecta' there were no significant differences between sites (Tables 45 and 46). When the data from the three varieties were polled (Table 47) there was no difference in yield parameters between plants close to or remote from hives.

Table 44. Effect of distance from hive on yield components of 'Aquarius'

Stem characters	420 metres from hive	10 metres from hive	LSD
Pod number	87.4	112.0	ns
Seed number	161.5	175.7	ns
Number seeds /pod	1.94	1.74	ns
Total seed weight	0.39	0.42	ns
Wt seed per 100 pods	0.47	0.42	ns
Harvest Index	0.11	0.13	ns

Table 45. Effect of distance from hive on yield components of 'Hunter River'

Stem characters	700 metres from hive	50 metres from hive	LSD
Pod number	100.1	107.9	ns
Seed number	307.1	264.4	ns
Number seeds /pod	2.93	2.50	ns
Total seed weight	0.74	0.64	ns
Wt seed per 100 pods	0.73	0.60	ns
Harvest Index	0.24	0.20	ns

Table 46. Effect of distance from hive on yield components of 'Trifecta'

Stem characters	500 metres from hive	20 metres from hive	LSD
Pod number	112.1	88.4	ns
Seed number	226.5	246.8	ns
Number seeds /pod	2.18	2.99	ns
Total seed weight	0.55	0.59	ns
Wt seed per 100 pods	0.52	0.72	ns
Harvest Index	0.16	0.19	ns

Table 47. Effect of distance from hive on seed yield components

Variety	Trifecta		Hunter River		Aquarius		Mean		
Stem characters	Remote from hive	Close to hive	Remote from hive	Close to hive	Remote from hive	Close to hive	Remote from hive	Close to hive	LSD
Pod number	112.1	88.4	100.1	107.9	87.4	112.0	99.9	102.8	ns
Seed number	226.5	246.8	307.1	264.4	161.5a	175.7	231.7	229.0	ns
Number seeds /pod	2.18a	2.99	2.93	2.50	1.94	1.74	2.35	2.41	ns
Total seed weight	0.55	0.59	0.74	0.64	0.39	0.42a	0.56	0.55	ns
Wt seed / 100 pods	0.52	0.72	0.73	0.60	0.47	0.42a	0.58	0.58	ns
Harvest Index	0.16	0.19	0.24	0.20	0.11	0.13	0.17	0.17	ns

Bees, tripping, and pod set

During the summer of 1999-2000 there was very little evidence in either Keith or Forbes of bees tripping flowers. When present in the field they were collecting nectar, not tripping flowers.

In December 1999 in both sites crops were setting pods well but there were no bees tripping flowers. Observations made on a windy morning in January, when the temperature about 20^0C indicated little evidence of bee activity or tripping and no automatic tripping was observed.

On another property, detailed observations were made on activity of bees over a one day period in January when crops were in full flower. In the morning the temperature had reached 40^0C and bees were not evident in the crops. During the afternoon, from 1 until 5 pm, the temperature averaged 34^0C and there was a wind of approximately 40 km/hr. Some bees were swarming, others remained clustered at the entrances of hives.

During this period there were no bees observed in any the 14 crops monitored. Nevertheless when flowers were observed closely, an average of 3% of open flowers had recently been tripped. One crop in which 12% of flowers had recently tripped had been watered three days previously, but five other fields which had also been recently irrigated showed no more evidence of tripping than fields awaiting water.

At the end of January bees were seen to trip 6% of flowers in one field., Other flowers were visited for nectar but flowers were not tripped. Despite the low frequency of tripping in lucerne, large numbers of bees were actively collecting pollen from skeleton weed and couch grass in the field. On a third property no bees were seen to trip flowers or collect pollen during observations in the summer of 1999-2000.

During observations for pod setting early in February 2000, plants setting large numbers of pods and plants setting few pods were examined to observe the amount of recent tripping on racemes still flowering. No bees tripped flowers during these observations. The data in Table 48 show that plants with a heavy pod set were the ones on which freshly tripped flowers were observed despite any evidence of bees tripping flowers. These data suggest that in each of these varieties there are plants which trip automatically under favourable conditions and also plants which do not trip automatically.

Table 48. Relationship between automatic tripping flowers and seed set

Variety	Seed setting ability	Number with many tripped flowers	Number with no tripped flowers
Hunter River	Good	6	0
	Poor	1	6
Siriver	Good	5	0
	Poor	0	5
Sirosal	Good	6	0
	Poor	0	5
Salado	Good	5	0
	Poor	0	5
Total	good	22	0
	poor	1	21

In March 2000 another study investigated the distribution of tripped flowers among good seed setting and poor seed setting plants in 'Siriver' at Keith. Notes were taken on a day when there were few bees in the field. The temperature was 23^0C. The data from 50 plants are shown in table 49.

Substantially more flowers were tripped on high seed setting plants than on low seed setters. In the absence of bees the tripping observed must have been largely automatic. The difference between the two groups suggests that high seed setters are those that are capable of a high level of automatic tripping. However on a few of the poor seed setting plants there were many tripped flowers. It is suggested that although these exhibit a high level of automatic tripping there are other restraints, such as female sterility which inhibited seed setting. Since plants are largely cross pollinated poor seed set should not be caused by poor pollen quality or male sterility.

In one field on one property at Keith approximately 25% of bees were observed to be tripping flowers and collecting pollen during peak flowering in January 2001. As there was a total of 2 to 3 bees working per square metre, approximately 1 per m^2 was tripping flowers at the rate of 8 flowers per minute. Despite this activity, at harvest time there was considerable variation among plants in pods set per stem and per raceme. Whether poor pod set was due to flowers being unattractive to bees, difficult for bees to trip, or female sterile or other cause was not determined. No bees were observed tripping flowers or collecting pollen in February 2001. On another property, 30% of bees were tripping flowers and collecting pollen from lucerne in January 2001 but not in December or February. On a third property at Keith, bees were collecting nectar and not tripping flowers.

In some varieties greater activity of bees collecting pollen in 2001 than in 2000 may have been reflected in an increase in number of pods per raceme (eg Genesis in Table 6, Hunter River , Table 8 in which number of pods, pod number per raceme and total seed weight were higher in 2001 than in the previous years and Salado (table 9) in which number of pods per raceme and seed weight per 100 pods changed. In other varieties such as Siriver, Pioneer L69 and Trifecta (tables 10, 14 and 16) there was no significant difference in yield components between 2000 and 2001. It is possible that these varieties contain more plants capable of automatic tripping than other varieties and thus rely less on pollinating insects for tripping and seed set.

At Forbes, activity of bees was observed in January 2000. In several fields there were 2 bees per m^2 but they were not collecting pollen or tripping flowers. When collecting nectar bees visited 19 flowers per minute. In February there was no evidence of bees tripping flowers but on one afternoon when the temperature was 27^0C considerable automatic tripping was observed especially in old flowers about 4 days since opening. In January 2001, when bees were only collecting nectar from lucerne, considerable automatic tripping was evident when the temperature was 23^0C at 10 am. Automatic tripping was observed on some plants which set very few pods. This suggests that in this case lack of tripping was not the reason for poor seed set. Female sterility may have contributed to low pod set.

Table 49. Flower number and number tripped, high and low seed-setting plants

Good seed setting plants		Poor seed setting plants	
Flowers/raceme	Number tripped	Flowers/raceme	Number tripped
2	2	2	1
4	4	5	0
3	2	4	0
3	0	2	1
4	2	1	1
6	4	4	1
4	4	5	1
4	4	5	2
3	2	3	2
3	2	7	1
2	2	10	6
5	1	5	1
5	4	3	0
3	0	9	6
7	4	10	0
4	1	5	0
3	2	4	1
3	2	4	0
3	1	4	1
6	2	2	0
6	2	6	1
4	3	3	0
5	0	3	0
4	1	3	3
2	3	4	4
Means			
3.9	2.2 (55% tripped)	4.5	1.3 (29% tripped)

In another area bees tripped only 1% of flowers visited in one field, and none in others while they collected nectar in January 2000. Although bees were not observed to trip flowers generally in early March 2000 they did visit recently tripped flowers and may have effected cross pollination in the process. On a bright sunny day and at 30^0C in early March, there was extensive automatic tripping observed while bees only collected nectar. Only in one field were 50% of bees tripping flowers and collecting pollen. Although this may have led to considerable cross pollination, this crop was harvested before the seed arising from bee pollination matured.

Observations of dense crops at full flower reveal the huge potential for seed set. Each stem may have 5 flowering racemes, which in a crop of 200 stems m^2 is 1,000 racemes. Each may have 10 flowers open, providing 10,000 flowers m^2 at one time. As flowering continues, additional flowers per raceme and racemes per stem develop providing some 100,000 flowers per m^2 over a few weeks. In a variety capable of setting 100 pods per stem and 1 g seed per 100 pods, and a stand of 200 stems per m^2 would require only 20,000 flowers to produce 20,000 pods and a yield of 2 t/ha seed crop.

Apart from the flexibility to produce a crop provided by such large numbers of flowers it is important to take account of the density of flowers at full flower. Racemes are distributed throughout the canopy at a density of one flower per cm^2. This provides the opportunity for pollen to be readily dispersed throughout the crop with automatic tripping. Alternatively, if bees trip flowers, 2 bees per m^2 each tripping 10 flowers per minute could trip 10,000 flowers per day. Thus a high seed yielding variety could be pollinated to produce a 1 t/ha crop in one day.

In the 1999-2000 lucerne seed production season very little flower tripping and cross pollination was observed to be effected by bees. This suggested that considerable amounts of self pollination might occur. To gain information concerning the levels of self and cross pollination under seed production conditions, white flowered plants (white flower colour being recessive to blue) were identified in fields during the season. Plants were allowed to open pollinate and seed was harvested when mature. Seed was sown in nurseries to allow observation of the flower colour of the progenies. The data from the progeny tests are shown in table 50.

It is clear from this table that there was very little self pollination in lucerne, only 5% on average, in the 1999-2000 season. Observations reveal that because bees were not tripping flowers cross pollination was not mediated by bees. This suggests that automatic tripping was of considerable importance during this season and that cross pollination was achieved by pollen moving within the crop canopy by means other than insect vectors.

Table 50. Flower colour in progenies of white-flowered plants

Plant number	Number of blue flowers	Number of white flowers	Percentage self pollination
1	13	2	13
2	22	2	8
3	32	0	0
4	46	5	10
5	38	1	3
6	27	6	18
7	46	6	12
8	59	2	3
9	13	0	0
10	26	1	4
11	24	0	0
12	52	2	4
13	49	2	4
14	15	0	0
15	54	1	2
16	77	11	12
17	22	3	12
18	23	0	0
19	33	0	0
20	36	1	3
21	14	0	0
22	9	0	0
23	38	0	0
24	41	0	0
25	63	4	6
26	60	1	2
Mean	35.8	1.9	5.1

Variation Within Varieties

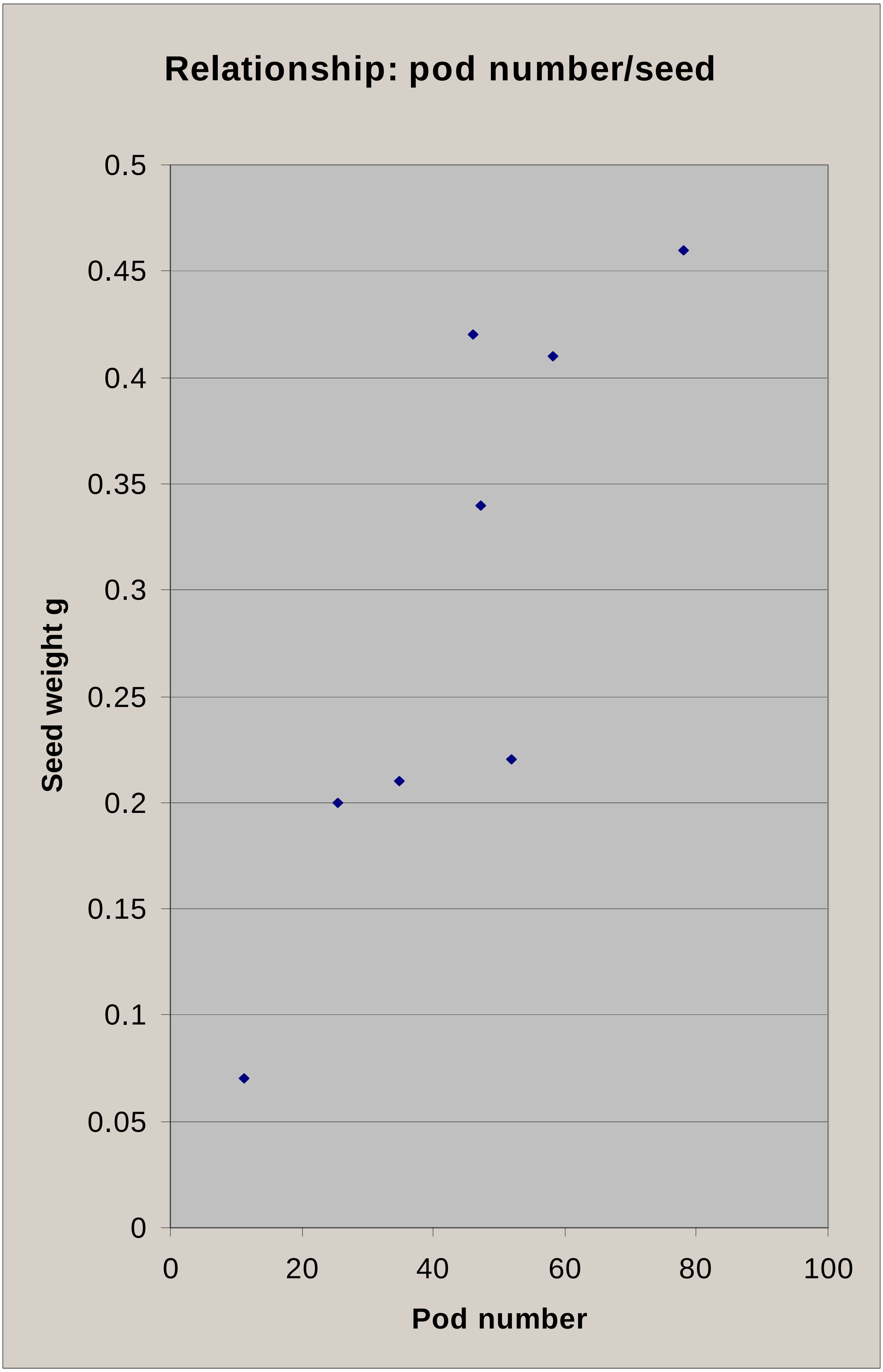
Apart from the variation observed among varieties, seasons, management, and other factors, it is important to note effects among plants within varieties. Although several plant characters were measured in the studies, two particularly important components of crop yield are: plant population (stand) or stems per hectare, and seed yield per stem. Seed yield per stem is the product of number of pods per stem and weight of seed per pod. These relationships are illustrated using a small sample of data collected in 1999. Figure 5 demonstrates that seed weight per stem is closely related to number of pods, and Figure 6 that seed weight per stem is determined by seed weight per 100 pods.

However varieties are a population of individual plants which may exhibit considerable variation in open pollinated species like lucerne. As an example, variation among 20 'Siriver' plants in seed yield per stem is illustrated in Figure 7. In all varieties examined typically 25% of plants produce 50% of seed yield. An indication of the variation in yield components in a range of varieties grown under irrigation in Forbes and Keith during the three years of this study is shown in table 51.

Table 51 Variation within varieties, mean and standard deviation

Variety	Location, Year	Pods/main stem	Pods per raceme	Total seed weight	Wt seed/ 100pods	Harvest Index
Genesis	Forbes1999	43 (32)	3.5 (1.8)	0.36 (0.35)	0.73 (0.28)	0.20 (0.11)
Genesis	Forbes 2000	27 (30)	2.6 (2.9)	0.12 (0.16)	0.16 (0.15)	0.04 (0.04)
Genesis	Forbes 2001	75 (37)	6.4 (3.1)	0.69 (0.46)	0.61 (0.26)	0.21 (0.08)
Genesis	Keith 1999	60 (22)	5.5 (1.1)	0.64 (0.39)	0.66 (0.28)	0.20 (0.04)
Genesis	Keith 2000	35 (29)	2.3 (3.7)	0.32 (0.32)	0.43 (0.22)	0.11 (0.09)
Genesis	Keith 2001	62 (35)	4.7 (1.9)	0.48 (0.33)	0.50 (0.18)	0.14 (0.04)
Aurora	Forbes 1999	47 (22)	5.4 (2.2)	0.34 (0.26)	0.51 (0.25)	0.16 (0.08)
Aurora	Forbes 2000	61 (29)	5.1 (3.3)	0.34 (0.12	0.34 (0.07)	0.14 (0.05)
Aurora	Forbes2001	58 (33)	5.9 (2.4)	0.40 (0.27)	0.43 (0.20)	0.16 (0.05)
Aurora	Keith 1999	37 (28)	5.0 (4.0)	0.59 (0.47)	0.71 (0.20)	0.17 (0.12)
Aurora	Keith 2000	29 (20)	2.5 (1.9)	0.26 (0.25)	0.48 (0.27)	0.14 (0.08)
Aurora	Keith 2001	42 (22)	4.4 (1.8)	0.33 (0.21)	0.49 (0.25)	0.13 (0.08)
Trifecta	Keith 1999	55 (20)	5.3 (2.1)	0.89 (0.56)	0.87 (0.27)	0.26 (0.10)
Trifecta	Keith 2000	43 (280	3.5 (2.1)	0.77 (0.64)	0.67 (0.39)	0.22 (0.15)
Trifecta	Keith 2001	57 (26)	4.4 (1.8)	0.99 (0.84)	0.79 (0.30)	0.21 (0.08)
Siriver	Keith 1999	58 (29)	6.2 (1.9)	1.05 (0.92)	0.71 (0.19)	0.19 (0.03)
Siriver	Keith 2000	79 (49)	7.7 (3.9)	0.61 (0.54)	0.56 (0.23)	0.15 (0.07)
Siriver	Keith 2001	58 (37)	6.5 (2.0)	0.58 (0.30)	0.71 (0.29)	0.17 (0.04)
Aquarius	Keith 1999	42 (24)	5.3 (2.3)	0.45 (0.31)	0.65 (0.17)	0.16 (0.07)
Aquarius	Keith 2000	52 (27)	4.3 (2.4)	0.51 (0.30)	0.60 (0.24)	0.19 (0.05)
Aquarius	Keith 2001	20 (16)	1.6 (1.1)	0.05 (0.06)	0.18 (0.10)	0.03 (0.03)
HunterRiver	Keith 1999	25 (12)	2.9 (1.3)	0.29 (0.24)	0.61 (0.12)	0.18 (0.07)
HunterRiver	Keith 2000	34 (19)	2.8 (1.5)	0.47 (0.56)	0.68 (0.24)	0.15 (0.10)
HunterRiver	Keith 2001	74 (24)	7.6 (3.1)	0.92 (0.40)	0.76 (0.17)	0.22 (0.02)

Figure 5 Relationship between seed weight and pod number



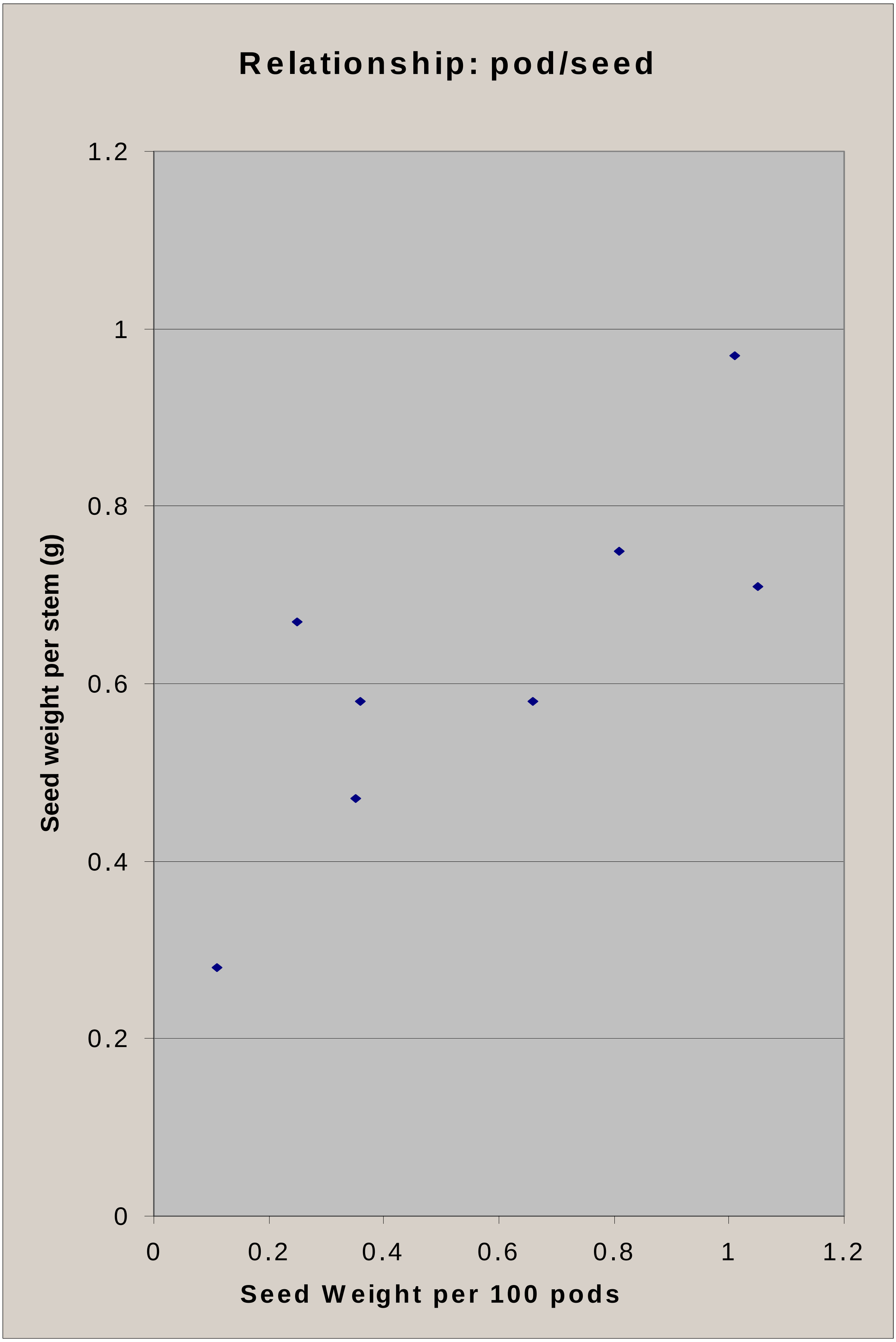


Figure 6 Relationship between seed weight and pod weight

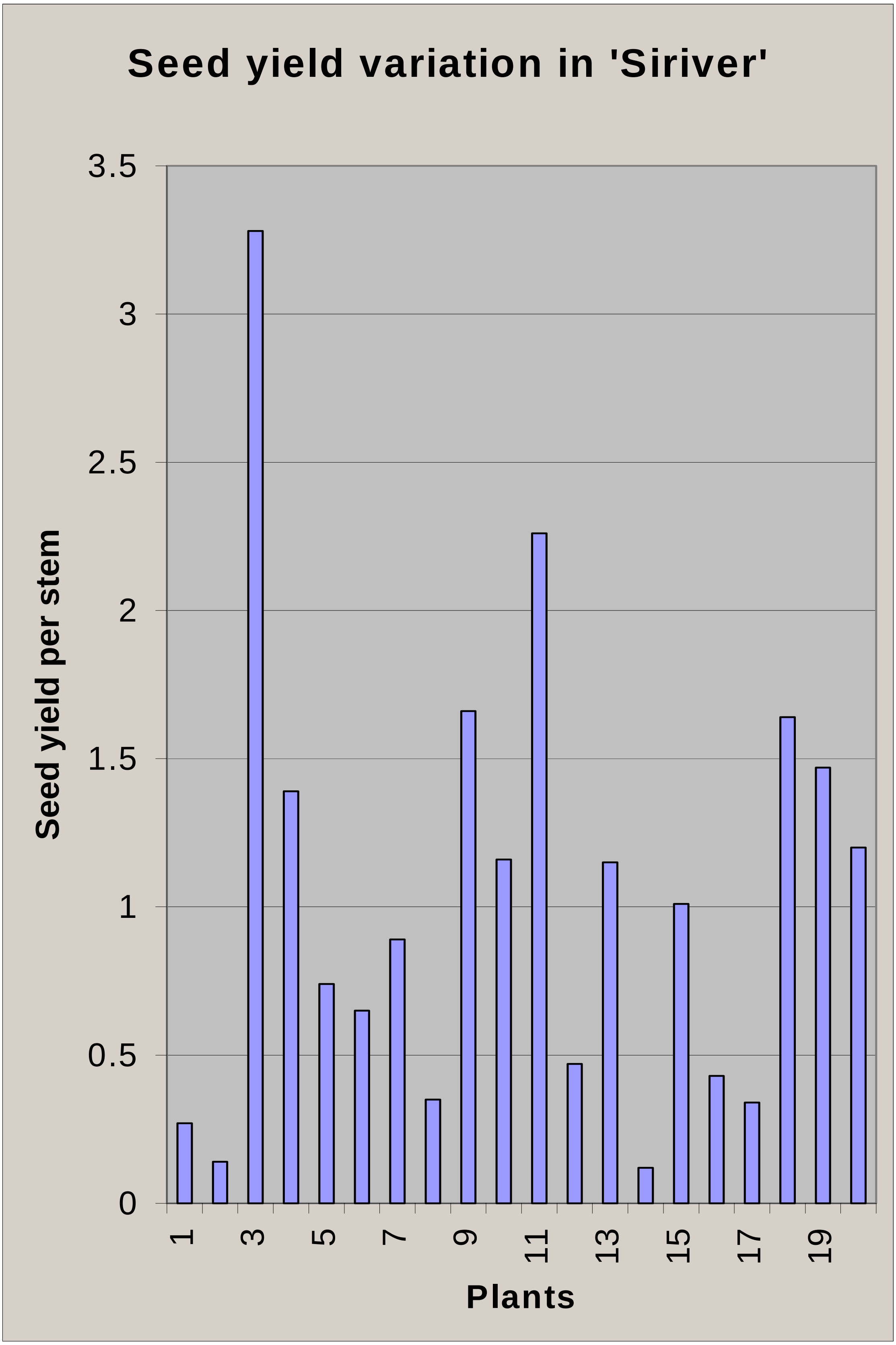


Figure 7 Seed Yield variation in Siriver

Selection Within Varieties

When considerable variation was observed among plants in lucerne seed production fields, an experiment was conducted to determine whether the variation was due to environmental effects or to genetic differences between plants. As crops were ripening, seed was collected from plants with a large number of well filled pods and from plants with very few pods in several varieties. Progenies of both high and low seed setting plants were evaluated in an irrigated nursery during the 1999-2000 growing season at Bordertown, SA to monitor the inheritance of characters related to seed production. Observations were made during the season and random samples collected from plants as the seed crops matured. Plants of high and low seed-setting plants were dissected to provide the data in the following tables.

Table 52 Progenies of selections in 'Aquarius'

Plant type	High seed setters	Low seed setters	LSD
Racemes on main stem	10.5a	14.6a	ns
Pods on main stem	44.5a	13.2b	19.1
Pods per raceme	4.37a	1.20b	1.84
Weight of seed on stem	0.17a	0.06a	ns
Total weight of seed	0.44a	0.31a	ns
Weight of seed per 100 pods	0.36a	0.20a	ns
Seeds per pod	1.55a	0.80a	ns
Total number of seeds	74a	23a	ns
Harvest Index	0.15a	0.05b	0.07

Table 53 Progenies of selections in 'Genesis'

Plant type	High seed setters	Low seed setters	LSD
Racemes on main stem	13.3a	11.8a	ns
Pods on main stem	40.7a	20.7b	10.8
Pods per raceme	3.14a	1.92b	1.13
Weight of seed on stem	0.21a	0.08b	0.08
Total weight of seed	0.91a	0.33b	0.58
Weight of seed per 100 pods	0.50a	0.35a	ns
Number of seeds per pod	2.09a	1.36a	ns
Total number of seeds	86a	32b	34
Harvest Index	0.15a	0.07b	0.06

Table 54 Progenies of selections in 'Hunter River'

Plant type	High seed setters	Low seed setters	LSD
Racemes on main stem	8.7b	12.0a	2.3
Pods on main stem	50.0a	20.6b	15.5
Pods per raceme	5.73a	1.74b	1.53
Weight of seed on primary stem	0.26a	0.10b	0.10
Total weight of seed on stem and branches	1.03a	0.74a	ns
Weight of seed per 100 pods	0.51a	0.47a	ns
Number of seeds per pod	2.11a	2.18a	ns
Total number of seeds	108a	44b	39
Harvest Index	0.22a	0.15b	0.06

Table 55 Progenies of selections in 'Siriver'

Plant type	High seed setters	Low seed setters	LSD
Racemes on main stem	11.6a	12.6a	ns
Pods on main stem	47.8a	34.2a	ns
Pods per raceme	4.01a	2.76a	ns
Weight of seed on primary stem	0.27a	0.20a	ns
Total weight of seed on stem and branches	1.06a	0.82a	ns
Weight of seed per 100 pods	0.55a	0.55a	ns
Number of seeds per pod	2.13a	2.34a	ns
Total number of seeds	109a	84a	ns
Harvest Index	0.19a	0.14a	ns

Table 56 Progenies of selections in 'Trifecta'

Plant type	High seed setters	Low seed setters	LSD
Racemes on main stem	10.9b	14.7a	3.8
Pods on main stem	40.1a	27.9a	ns
Pods per raceme	3.64a	1.88b	1.46
Weight of seed on primary stem	0.25a	0.14a	ns
Total weight of seed	0.78a	0.48a	ns
Weight of seed per 100 pods	0.61a	0.39a	ns
Number of seeds per pod	2.70a	1.43b	1.23
Total number of seeds	108a	58a	ns
Harvest Index	0.17a	0.09a	ns

Table 57 Summary Analysis

Plant type	High seed setters	Low seed setters	LSD
Racemes on main stem	11.1b	13.6a	1.5
Pods on main stem	45.4a	25.1b	6.4
Pods per raceme	4.31a	1.94b	0.59
Weight of seed on primary stem	0.24a	0.12b	0.05
Total weight of seed on stem and branches	0.85a	0.70a	0.23
Weight of seed per 100 pods	0.51a	0.38b	0.09
Number of seeds per pod	2.14a	1.61b	0.35
Total number of seeds	97.5a	50.6b	19.2
Harvest Index	0.18a	0.10b	0.03

The mean value for various characters in the high seed setting progeny for each of the five varieties is shown in table 58.

Table 58. Mean values and (standard deviation) for characters measured in five varieties subjected to one cycle of mass selection.

Character	Aquarius	Genesis	Hunter River	Siriver	Trifecta	mean
Racemes on main stem	10.5 (1.7)	13.3 (1.9)	8.7 (1.6)	11.6 (3.7)	10.9 (2.9)	11.0 (2.4)
Pods on main stem	44.5 (22.0)	40.7 (9.3)	50.0 (21.2)	47.8 (25.0)	40.1 (22.0)	44.6 (19.9)
Pods per raceme	4.4 (2.3)	3.1 (0.9)	5.7 (2.2)	4.0 (1.9)	3.6 (1.6)	4.2 (1.8)
Weight of seed on main stem	0.17 (0.16)	0.21 (0.10)	0.26 (0.13)	0.27 (0.16)	0.25 (0.20)	0.23 (0.15)
Total weight of seed	0.44 (0.21)	0.91 (0.75)	1.03 (0.78)	1.06 (1.22)	0.78 (0.58)	0.84 (0.71)
Weight of seed per 100 pods	0.36 (0.19)	0.50 (0.22)	0.51 (0.19)	0.55 (0.19)	0.61 (0.37)	0.51 (0.23)
Number of seeds per pod	1.5 (0.7)	2.1 (0.9)	2.1 (0.8)	2.1 (0.9)	2.7 (1.4)	2.1 (0.9)
Harvest Index	0.15 (0.08)	0.15 (0.06)	0.22 (0.07)	0.19 (0.08)	0.17 (0.08)	0.18

The genetic gain through selection was calculated as the difference in the value of a character in the high seed setting progeny from the mean of the high and low populations. The genetic gain from one cycle of mass selection in each of five varieties is shown in table 59.

Table 59. Genetic gain (%) in five varieties subjected to one cycle of mass selection.

Character	**Aquarius**	**Genesis**	**Hunter River**	**Siriver**	**Trifecta**	**mean**
Racemes on main stem	-16	6	-16	-4	-15	-9
Pods on main stem	55	33	42	17	18	33
Pods per raceme	57	24	54	19	32	37
Weight of seed on main stem	49	44	46	15	29	37
Total weight of seed	16	48	16	13	23	23
Weight of seed per 100 pods	29	17	4	0	22	14
Number of seeds per pod	31	21	0	0	31	17
Harvest Index	49	37	19	13	28	29

Discussion

During this project,

- Lucerne varieties were found to differ in seed yield and in reliability of production and it was concluded that there is a need for trials in which varieties are compared to allow the most productive ones to be identified.
- When the expectation that bees trip flowers and contribute to seed production was examined, it was found that although bees are present in crops they collect nectar rather than pollen. However as many plants trip automatically it is likely that varieties, which do not need bees for pollination, can be developed.
- Additional variation in lucerne varieties was explored and it was found that selection for seed yield can be readily achieved, suggesting that more productive varieties can be developed.
- Currently seed crops are irrigated in summer but as water is used inefficiently under hot conditions the potential to produce comparable crops in the cooler conditions of spring should be examined.

The findings are discussed in more detail below.

Effect of Seasonal Conditions

In each of the fields monitored over three years, the numbers of plants remained reasonably constant and variation in performance over time was due to environmental effects modifying seed production on a constant number of stems. This made it possible to observe how different seasonal conditions affected the performance of the varieties grown. However, to some extent, demonstration of differences due to season was masked by the considerable variation among plants within varieties. Variation in numbers of plants within and between fields made it difficult to estimate yield potential and to compare yields of crops in different fields in any year. Differences due to stand were confounded with differences due to variety or management. Consequently for comparisons between fields, it was necessary to consider differences between individual stems, and ignore numbers of stems. Therefore in these studies the individual stem was the unit studied and analysed. Numbers of racemes, numbers of pods, weight of seed per pod, total seed weight and harvest index were used to indicate differences between lucerne plants in different fields, varieties and years.

Considerable variation in seed yield between fields and years was observed. Some stems produced a relatively small number of racemes of flowers and flowering stopped. This was particularly noticeable at Keith in 1999. The most likely interpretation is that conditions favoured pod set in 1999, and with a heavy pod set the plant devoted resources to pod fill instead of additional stem growth and flower production. It is also possible that on some occasions hot and dry conditions may have adversely affected further stem and flower production (Engelbert, 1932).

A different pattern was observed in 2000 when the number of pods set per raceme tended to be lower in some varieties, the plant producing additional racemes to compensate. The production of additional stem to support continued flowering reduced the harvest index. On other varieties there was a high initial pod set and flowering stopped. It appears that these varieties were adequately pollinated under conditions that did not favour pollination in other varieties. It is possible that the flower structure (Larkin and Graumann, 1954) is such that automatic tripping is more readily achieved in varieties which reliably set pods irrespective of conditions.

Over the three years of observations some varieties exhibited a consistent performance in pod set, total seed weight, pod weight and harvest index, and other varieties varied considerably in performance from year to year. Some of the differences may be attributed to management decisions but some are likely be due to specific varietal features contributing to seed production under certain circumstances.

For example, in dry land crops monitored at Keith, performance of 'Siriver' (Table 24) and 'Hunter River' (Table 25) was relatively stable over three years for total seed weight, seed weight per pod and harvest index, while less stability was exhibited by 'Genesis' (Table 27). Data indicate that performance of some varieties is more stable than others under both irrigated and dry land conditions.

At Forbes also, there were differences between varieties in yield parameters over the years of this study. 'Aurora' data for example are shown in Tables 5 and 19. In one site the number of pods, number of pods per raceme, total seed weight, seed weight per pod and harvest index were relatively constant and low. At the other location, the parameters were stable at a higher yield level.

In contrast, 'Genesis' performed well at three sites in 1999 but in 2000 the seed weight per pod was very low. However the number of pods set, including the number of pods per raceme, was high at two sites and low at a third. In all cases the harvest index was low in 2000. The results indicate that flowers were tripped but there was a deficiency of fertile pollen to ensure fertilisation of available ovules. Variation in the performance of 'Genesis' at both Keith and Forbes suggests that the fertility of this variety is variable. Sexsmith and Fryer, (1943) noted that plants differed in pollen viability.

The variable performance of some varieties in different seasons provides difficulties in predicting lucerne seed yield. Others showed a degree of stability between districts and seasons. The varieties with a broad adaptation to conditions are more desirable than the variable ones if yield stability is required. There was also variation within years indicating that performance is affected by local factors such as soil, management and irrigation timing.

Effect of Management

In dry land crops at Keith, stand was low with a total of 100 or less stems per m^2 carried on as few as six plants per m^2. The low number of plants in non-irrigated fields is due to plant loss during extended dry periods in summer. If high seed yields are to be achieved under dry land conditions it is likely to be in the sowing year or possibly the second year after sowing before stand is depleted. On heavier and deeper soils with a greater ability to retain soil moisture, and in regions with summer rainfall, higher plant and stems populations may be retained. Under these conditions there is a higher dry land yield potential.

Number of plants varied considerably in irrigated crops but was commonly in the range of 150 to 200 stems per m^2. There was a tendency for crops to compensate for poor stand by producing more stems from the crown to maintain a fairly constant number of stems per m^2 (Figure 2). Lower populations can be expected to have low yield and the highest yield observed, 1400 kg per ha, was obtained on a crop with a high stand, - 320 plants per m^2. Not only is a high plant population important to achieve a high yield because of the potential contribution of numbers of pods per stem and seeds per pod, a dense stand is less prone to blow in the wind. In several fields with relatively low numbers of stems, plants were observed to be buffeted in the wind and this caused considerable loss of pods. Excellent seed yield was often observed on prostrate plants, partly because the seed crop was not reduced through wind causing pods to drop. On the other hand, some dense fields held a primary seed crop and regrowth flowered to provide a double crop. Such mixtures are prone to lodge, providing difficulties at harvest time. Seed crops in Australia are drilled in narrow rows giving a complete sward, not in the widely spaced rows recommended for high yield in California (Peterson, 1972).

A large number of factors have to be taken into account when crop management is considered. When two dry land fields of 'Aurora' grown at Keith are considered, (Table 28), total seed weight was low in 1999, and seed weight per pod was low in both sites. It appears that pollination and fertilisation were poor and that at one site there was compensation through higher pod set. In 2000, seed weight per pod was high in Field 1 and low in Field 2 again reflecting a low level of ovule fertilisation in field 2.

Performance was comparable and good in both fields in 2001. Management or location conditions have different effects in different years.

Further comparisons were made in irrigated crops of 'Aurora' at Keith in 1999 and 2001 (Table 32). In this case there was no significant difference between sites or years except that in one location in 1999 there were fewer racemes produced. However these racemes carried the greatest number of pods indicating that conditions favoured tripping on this occasion. This supports the observation earlier that when a good pod set is obtained the plant supports pod development rather than production of more flowers.

When irrigation treatments were applied to 'Siriver' in 1999 (Table 29) there was no significant difference in yield components with one or several irrigations at one site. At the other site the total seed weight was reduced by providing only one irrigation, and seed weight per pod and harvest index were reduced. It is likely that the precise timing of the one irrigation was a key difference between the treatments. However, the fact that a crop supplied with only one application of water performed as well, on a single stem basis, as a fully irrigated crop, warrants further testing.

When three water regimes were imposed: dry land, one-irrigation and full-irrigation on a crop of 'Hunter River' in 1999 (Table 30), the only significant difference among yield components was fewer pods per raceme in the dry land crop. The fact that the dry land crop was earlier flowering than the irrigated crops, and the total seed weight, and the seed weight per pod were not reduced under the cooler late spring conditions is important. There is cause to explore possibilities of irrigated spring lucerne seed crops which would be largely grown on stored soil moisture from winter rains and likely to use less water because of lower evaporative conditions in spring.

An irrigated and a dry land crop of 'Aurora' were compared at Forbes (Table 31). There were no significant differences between the crops in any yield components measured. Comparisons were made on a 'per stem' basis but as dry land crops normally have fewer stems per hectare than irrigated crops do, the yield per hectare would be lower in a dry land crop.

Comparisons were made between different types of irrigation - overhead pivot spray, and border check flood irrigation on two varieties. In one case (Table 34) there was no difference except for fewer racemes produced with overhead sprays. In the other case (Table 33) two fields of 'Siriver' were compared. There was a lower pod weight and harvest index with overhead sprays. There is the possibility that overhead irrigation washed pollen from flowers, (Hadfield and Calder, 1936), reducing the amount available to fertilise flowers. In some respects overhead sprays applied at flowering time can have a similar effect as rain, which is disadvantageous at flowering (Spafford, 1938).

The performance of 'Genesis' at Forbes and Keith was compared in Table 35. The total seed weight did not vary between locations but the seed weight per pod was lower at Forbes in both 2000 and 2001. This is an indicator of lower fertilisation of ovules possibly through inadequate amounts of pollen available. This is likely to be the case after rain at flowering time. However there was no difference between locations in harvest index, it being lower in 2000 and 2001 than in 1999 in both sites. It is probable that limited fertilisation and lower seed weight per pod led to surplus assimilates being available for vegetative growth and this reduced the harvest index in 2000 and 2001.

Effect of Variety

Comparison of two varieties for two years with overhead irrigation (Table 37) indicated differences in seed weight per pod which affected total seed weight in one variety. It is possible that this is not a varietal effect but rather due to spray irrigation removing pollen lodged on the flowers and thus reducing the pollen pool, (Hadfield and Calder, 1936), and chances of fertilisation of some ovules when flowers tripped. This appears to be a similar effect to that observed in the case of 'Siriver' (Table 33) discussed above. It suggests that definitive studies should be conducted to investigate possible pollination/fertilisation problems due to overhead irrigation. In the mean time it would be prudent to minimise use of overhead irrigation at flowering time in lucerne seed crops.

When performances of three varieties were compared under dry land conditions at Keith in 1999 no significant differences were observed except for a slight difference in seed weight per pod. Variation within varieties was so high that no differences were detected in total seed weight (Table 38). A similar slight difference in seed weight per pod was noted when a further three varieties were compared at Keith (Table 39). In another two varieties (Table 40) under similar conditions no differences were detected. It was difficult to detect differences between varieties under dry land conditions because of the considerable variation within varieties.

When the performances of 'Genesis' and 'Aurora' were compared over three irrigated crops at Forbes, and some of the variation within varieties extracted statistically, the only difference was in total seed weight, with 'Genesis' superior to 'Aurora' (Table 41). A comparison of performance of irrigated crops of 'Aquarius' and 'Salado' after three years at Keith failed to show any differences between the varieties except number of racemes (Table 42), but when 'Aquarius' and 'Siriver' were compared (Table 43) 'Siriver' was superior in all yield components except number of racemes. Differences between varieties can be demonstrated, either in stability of performance or on a seasonal basis. However there can be considerable variation between fields of one variety in any year demonstrating that differences can also be attributed to management or environmental effects. Very large differences between seasons as between 1999 and 2000 at Forbes can be attributed to rain which caused commercial yields to exhibit three-fold differences between years. Although such differences may be exceptional, average yields of 604 kg/ha in 1999 were followed by 130 kg/ha in 2000. This seasonal difference was much more significant than observed differences between fields and varieties.

Part of the variable performance of varieties lies in the variation within varieties with respect to pod set and weight of seed produced per pod. Pod set depends on tripping of flowers which is affected by a range of stimuli, and seed numbers in pods is modified by pollen availability, and fertilisation of ovules. These factors are discussed below.

Pollination

Lucerne seed growers contract beekeepers to provide hives of honey bees in seed production fields so that bees will trip lucerne flowers, and in the process, move pollen from one plant to another, effecting cross pollination. However, observations during this study and numerous reports in the literature indicate that bees have a tendency to only collect nectar from lucerne flowers, without tripping the flowers and ensuring cross pollination.

During the 2000 season observations were made on three lucerne seed crops at Keith to determine the effect of distance from hives on parameters affecting seed set. Data in Tables 44-47 indicate that there was no difference in parameters affecting seed yield between locations close to hives and points 400 to 700 metres away in any of three varieties. The data support field observations of almost no tripping of flowers by honey bees during the 2000 season. Although bees were present in crops they were collecting nectar without tripping the flowers and were therefore transferring very little pollen between flowers except when they visited flowers that had already been tripped. These findings support those of Maelzer and Pinnock (1983) who found no relation between lucerne seed yield and bee numbers in South Australia. Tysdal (1940) and many others have observed that honey bees trip very few flowers unless there are no other pollen sources available (Vansell and Todd, 1946). Doull (1961) reported that in South Australia red gum competes strongly with lucerne as a preferred pollen source for bees. During 2000, bees were seen to be actively collecting pollen from couch grass and various weeds in lucerne fields, rather than from lucerne.

Although bees were rarely observed to trip flowers, large numbers of flowers tripped automatically particularly on mild sunny days but not under hot or windy conditions. Automatic tripping has frequently been observed since early reports (eg Kirk and White, 1933). Stevenson and Bolton (1947) considered automatic tripping might be useful in plant breeding if inbreeding could be avoided.

Observations were made in the field in February to seek a relationship between automatic flower tripping and seed set. In four varieties, plants which were setting many pods and plants with little pod set were identified. When plants were scored for degree of automatic tripping on currently flowering racemes, it was clear that the plants with extensive tripping were the ones with large numbers of pods set (Table 48). This result is in accord with the conclusion of Armstrong and White (1935) that self-tripping largely determines the differential seed setting capacity of lucerne plants. In a more detailed subsequent study the total numbers of open flowers and the numbers of tripped flowers were compared on 25 plants with good pod set and 25 plants with poor pod set (Table 49). There were approximately twice as many tripped flowers on plants with good pod set as on poor seed setting plants.

These observations indicate that plants with high seed yield possess flowers which readily trip automatically. These plants do not require to be cross pollinated by bees but the question arises as to whether or not automatic tripping lead to self-pollination which is known to lead to progeny which are weak vegetatively and weak in seed production (Hadfield and Calder, 1936). Dwyer and Allman (1932) reported that it was generally accepted that tripping by insects contributes to cross pollination but that automatic tripping leads to self pollination.

To resolve this issue seed was collected from white-flowered plants in seed production fields in 2000, a year when bees were rarely observed to trip flowers or collect pollen. White flower colour is controlled by recessive genes. As pollination was not controlled, the progeny of white flowered plants would be expected to have white flowers if arising through self pollination and blue if cross pollinated. When progenies from white flowered plants were grown (Table 50) there was evidence of only 5% self pollination and 95% cross pollination. This level of cross pollination is similar to that observed by other investigators (eg Knowles, 1943 and Bolton, 1948). This indicates that despite lack of bee activity, and with considerable automatic tripping, seed arises from cross pollination. This provides an additional question as to how is pollen transferred from one plant to another to effect cross pollination.

Dwyer and Allman (1932) found that when lucerne flowers were tripped, pollen was spread in a circle 25 cm in diameter. Hadfield and Calder (1936) observed pollen on the standard petals of untripped flowers and on microscope slides suspended in the crop. When it is realised that a dense crop may have approximately 10,000 flowers open per m^2 at full flower there is the potential for numbers of pollen grains to be drifting through the crop and providing the potential to fertilise tripped flowers.

Variation in weight of seed per pod reported in this study warrants consideration in relation to fertilisation. Cooper et al (1937) and Tysdal (1940) found higher pod set and more seeds per pod with cross- compared with self-pollination. Doull (1961) deduced that pods resulting from self-pollination contain only one or two seeds compared with up to 12 seeds per pod with cross pollination. Although self pollination may lead to few or no seeds per pod through incompatibility (Viands *et al*, 1988) and ovule abortion (Sayers and Murphy, 1966), it is possible that low numbers of seed per pod can be traced to other causes. There is likely to be a deficiency of pollen grains on standards of flowers if it is washed away by rain or spray irrigation, and in a poor stand with wind movement removing pollen.

Variation within Varieties

Variation within varieties has been mentioned in the context of some plants being capable of automatic tripping and producing a good pod set while other plants are less productive. Pod number has been shown to be related to seed yield and weight of seed per pod to seed weight per stem. The variation in 'Siriver' for seed yield per stem was illustrated in Figure 7. This is in accord with the variation in all varieties examined, that 25% of plants produced 50% of the yield, with the balance (75%) of plants producing much less seed. Some plants in all varieties continued to flower without setting any seed. Mean values and the standard deviation with respect to key parameters affecting yield are shown for a range of varieties at Keith and Forbes (Table 51). This variation suggested that it should be possible to select for increased seed production.

To evaluate the possibilities of selecting for high and low seed yielding plants, plants setting large or small numbers of pods were identified in production fields and seed was collected at maturity. In this mass selection process plants were open pollinated so that although there was selection pressure on the female parent for high or low seed production, the pollen was contributed randomly, presumably from both high and low seed setting plants. If the selection aim is to increase the seed production with the aim of developing a variety, conventional breeding procedures would be used. For example desirable plants would be removed and grown in isolation so that selected high seed setting 'female' plants would be exposed only to pollen from other desirable plants.

Differences between progenies of high and low seed yielding plants in five varieties are shown in Tables 52 to 57. The greatest response to selection was in number of pods on the main stem and number of pods per raceme. However the variation within selections was so great that it was difficult to demonstrate statistical differences in some characters, between high and low selections. When all varieties were considered together (Table 57) the high and low selections were shown to be different in all characters. This indicates that selection was effective in modifying the parameters affecting lucerne seed production and that breeding for increased seed yield would be successful.

The mean values and the standard deviation for the parameters related to seed yield in the high seed yielding population are shown in Table 58. The weight of seed produced was higher on 'Hunter River' and 'Siriver' than on other varieties and this was related to the number of pods set on the main stem. The standard deviation was high for most characters, indicating opportunities to further modify varieties by selection. The genetic gain realised by one cycle of mass selection was very high, averaging 30% or more for such characters as pod number and seed yield. Less progress was made for seed weight per pod and numbers of seeds per pod.

It is likely that progress in selection for pod set reflects selection for plants capable of automatic tripping as tripping is an essential component in pod setting. Seed number and weight per pod may be amenable to selection if attention is paid to incompatibility and sterility factors but there is a considerable impact of environmental on fertilisation the prerequisite for seed development. Quality of pollen may be reduced by cold or moisture stress and quantity may be reduced through poor plant stand, wind or rain.

Conclusions

This study has revealed that some lucerne varieties are capable of high and reliable seed yield and others are more variable in performance. However production of all varieties is dependent on management and seasonal conditions. Weed control and pest control were of a high order and irrigation management was sound. A very strong adverse effect is provided by rain at flowering time as it reduces fertilisation and seed numbers in pods. In some fields potential yields were not achieved because of inadequate numbers of plants, particularly in old stands.

The characteristics of a good variety include a high and stable yield with flowers that trip readily and a heavy crop of well-filled pods on approximately ten racemes. It is likely to have a high proportion of plants with flowers that trip readily and automatically. It is unlikely to have branches high on the stem as these compete with pod development. An improved variety is also likely to be uniform with few of the poor seed producing plants which reduce yield potential of current varieties.

For potential yield to be realised, there should be an excellent dense stand of stems with good weed and pest control, preferably under the care of an experienced crop monitor. The crop should not be watered heavily in the bud stage but watered about flowering time as the combination - moist soil and dry air promotes tripping. Pod set is likely to be greatest in dry, mild, sunny weather. Dry conditions are essential for good fertilisation of flowers. Dry weather is essential as the crop matures because wet conditions cause pods to drop and split, and seed can germinate or weather.

If varieties are modified to produce higher yields of seed, the cost of seed is likely to decrease, encouraging more farmers to sow lucerne in dry land salinity control programs.

Varieties with a strong automatic tripping capacity are likely to reduce the costs and variability induced by dependence of honey bees for pollination. If irrigation management is changed towards the production of seed crops in spring instead of in summer, water will be used more efficiently and provide the potential to irrigate additional areas.

Additional research is desirable in a reassessment of the effectiveness of honey bees as pollinators and in the evaluation of the potential of irrigated spring cropping for seed production.

Implications

Crop Establishment and Management

The research reported here has emphasised that seed yield is determined by the product of two components, number of stems and yield per stem. Emphasis was placed on yield per stem which reflects the organization within the plant, with consideration of flower production, tripping of flowers, pod set and seed production in the pod. These are characters which are modified by environmental conditions and by the genetic constitution of the plant.

The number of stems in a seed production field is affected by crop establishment, losses due to disease and moisture stress, and management practices. Differences in stand or plant population between different fields of the one variety can have a large effect on variation in yield.

It is important that seed growers ensure that their fields carry an adequate stand. Therefore effective crop establishment is essential and superior grazing management is needed to avoid plant losses. Plant diseases such as lucerne yellows also cause loss of stand and should be controlled, and management of both beneficial and destructive insects is important. As this requires the judicial use of the diversity of agricultural chemicals available, more growers should obtain input from specialist independent crop monitors. The cost of this would be easily recouped through better management practices as, if it is necessary to replace a depleted crop after two years instead of four, there is a new establishment cost of $400 per hectare and additional losses are incurred while the land is out of production.

Selection of Varieties

There is variation in performance of varieties within and between farms. Plant stand, timing of irrigation, soil characteristics and other management practices have a bearing on varietal performance.

Over the three years of study some varieties exhibited a consistent performance in pod set, total seed weight, pod weight and harvest index and other varieties varied considerably in performance. The data indicate that performance of some varieties is more stable than others under both irrigated and dry land conditions. There was also variation in performance of a variety growing in different fields, in the one year, demonstrating that production is affected by local factors such as soil, management and irrigation timing. The varieties with a broad adaptation to field conditions appear desirable if yield stability is required.

In view of the large number of varieties grown already and the continued development of new ones, it is important that trials be conducted in seed production districts to assess seed yield potential and longevity of varieties. This will allow growers to identify the most appropriate varieties. Some varieties may have twice the seed yield of others, returning an additional $1000 per hectare.

Breeding

When considerable variation in pod set was observed within individual crops in the first year of the project, a research study was undertaken to establish whether variation was due to environmental conditions or to genetic differences among individual plants. Seed from both high and low seed setting plants was sown in a nursery near Bordertown, South Australia where progeny evaluation revealed that yield components had increased substantially with selection.

The data presented here indicate that there is sufficient variation in lucerne varieties for seed yield to be increased substantially by selection and breeding. This would make seed production more profitable and would allow seed to be produced at very competitive prices for export markets. With superior varieties and good management, yields of one tonne per hectare with a value of $3000 should be achieved, a three fold increase over current yields and returns of $1000/ha. Better growers already achieving 1 tonne/ha can also expect an increase in returns.

Pollination

The investigation has shown that the practice of using honey bees as pollinators, costing seed producers about $600,000/year in hire costs, is of doubtful value. Similar observations have been made in Australia and overseas for the last 70 years. However as many seed producers consider that bees are necessary, further studies are warranted to determine the effectiveness of honey bees as pollinators.

During the 2000 season observations revealed that there was no difference in seed yield between locations close to and remote from hives. Although bees were present in crops they were collecting nectar without tripping the flowers and were therefore transferring very little pollen between flowers. Bees were seen to be actively collecting pollen from couch grass and weeds and not from lucerne.

An alternative pollinating service may be provided by the use of leaf-cutter bees, the potential of which is currently being studied. To replace the need for insect pollinators there appears to be considerable potential in the development of varieties capable of automatic tripping. Many plants in currently available varieties trip automatically and their frequency can be increased by selection and breeding.

Irrigation practices

This report showed that seed yield per stem is similar in dry land crops in spring, and summer crops which are irrigated four or five times using 600 mm of water. The potential of spring irrigated seed crops, using 200 mm water, should be investigated. More efficient water use would provide an increase in area irrigated. Irrigated spring crops should lead to a three-fold increase in production worth $45million in lucerne seed exports compared with $15million at present. Spring crops also avoid seed wasp attack which currently reduces export returns by $5million/year.

When overhead irrigation was used there was evidence of reduced numbers of seeds per pod, reflecting lack of fertilisation of ovules. A greater effect of water was observed at Forbes when rainy conditions depressed yield substantially in 2000 by reducing seed weight per pod. It was concluded that rain washes pollen from the crop canopy, reducing the availability of pollen to effect fertilisation.

The adverse effect of rain suggests that seed growers should attempt to spread the risk of rain reducing yield by ensuring that various crops pass through the sensitive flowering phase at different times by staggering closing up times.

Recommendations

Crop Establishment and Management

Lucerne crops are used for various purposes, for hay, grazing and some are harvested for seed. Seed yield depends on numbers of plants, and particularly on number of plant stems per hectare. For irrigated crops at least 200 stems per m^2 are required to realise high seed yields.

- Growers should take care in sowing to obtain a thick stand of plants
- Rotational grazing should be used to retain stand
- Effective treatments for insect and disease attack should be used
- Crop monitors should be employed to advise on appropriate management strategies
- Disease resistant varieties should be planted to minimise losses and maintain seed potential

Selection of Varieties

Varieties vary in their seed yield and in the reliability of their seed production.

- Varieties should be evaluated for seed production as well as for fodder production
- For reliable results varieties should be included in trials for three years and in diverse sites
- Trials should be conducted by independent operators

Management of Pollination

Seed production depends upon flowers being tripped and cross pollinated.

- Seed growers should evaluate effectiveness of honey bees in tripping flowers
- Seed growers should consider benefits of honey bees against cost of $600,000 per year
- Potential of leaf-cutter bees to increase yield should be costed
- Growers should seek varieties with automatic tripping to remove need for pollinating insects

Breeding New Varieties

Breeders can lower seed production costs and increase returns to seed growers by selective breeding.

- Breeders should select varieties for increased seed yield
- Development of varieties with high levels of automatic tripping should be undertaken to reduce cost of pollinators
- Varieties with multiple resistances should be bred to reduce stand loss
- Germplasm should be evaluated to reduce weather losses in mature crops awaiting harvest

Evaluation of Irrigation Practices

Irrigation costs are increasing and water quality and quantity are decreasing suggesting that alternative irrigation strategies should be evaluated by lucerne seed producers

- Dry land seed crops should be considered to complement irrigated crops
- Spring seed crops should be evaluated to conserve water and reduce seed wasp losses
- Water use efficiency in spring and summer seed crops should be examined
- Growers should consider having crops mature at different times to spread loss risk
- Water stress to stimulate flowering should be evaluated as a management tool
- Possible detrimental effects of overhead watering at flowering time should be examined

Appendices

Appendix 1

Presentation to Lucerne growers at Keith and Forbes 2000/2001

Slide 1

Evaluation of Lucerne Varieties for Seed Yield

Dr Ross Downes
Innovative Plant Breeders

Supported by RIRDC
Pasture Seed Program

Slide 2

Relative Seed Yield of Lucerne Varieties

Variety	Kg/Ha	%
Siriver	605	100
Sequel	482	80
Trifecta	444	73
Hunter River	416	69
CUF 101	420	69
Aurora	335	55
Hunterfield	243	40

Sardi certified seed statistics (Mid 90's)

Slide 3

Factors Affecting Variation in Seed Yield

- Timing
- Stand
- Weather
- Irrigation management
- Soil type
- Pests
- Variety
- Pollination

Slide 4

Seed Yield

- 25% of plants give 500 Kg/ha
- 75% of plants give 500 Kg/ha

- **Total 1000 Kg/ha**

Slide 5

Seed Yield

- 25% of plants give 50% of yield
- 75% of plants give 50% of yield

Slide 6

Potential Seed Yield

- 25% of plants give 500 Kg/ha
- 75% of plants give 1500 Kg/ha

Total 2000 Kg/ha

Slide 7

Selection for Seed Yield

Variety	High Yield Seed g/stem	High Yield H Index	Low Yield Seed g/stem	Low Yield H Index
Siriver	1.06	0.22	0.82	0.16
Sequel	0.89	0.17	0.70	0.12
Trifecta	0.78	0.20	0.48	0.13
H River	1.03	0.21	0.74	0.16
Genesis	0.91	0.17	0.33	0.10
Aquarius	0.44	0.15	0.31	0.06
Mean	**0.85**	**0.19**	**0.56**	**0.12**

Slide 8

Selection for Seed Yield

Variety	High Yield Pod #	High Yield Seed/Pod	Low Yield Pod #	Low Yield Seed/Pod
Siriver	48	2.3	34	2.4
Sequel	50	2.2	34	1.8
Trifecta	40	2.9	28	2.1
H River	50	2.2	21	2.1
Genesis	41	2.1	21	1.5
Aquarius	44	1.7	13	1.7
Mean	**45**	**2.2**	**25**	**1.9**

Slide 9

Factors Affecting Pod Set

- Flower Abortion
  - High temperature
  - Low moisture
- Competition from shoots
  - Excess moisture
  - New vegetative growth
- Tripping of flowers
  - Automatic
  - Bees

Slide 10

Pollinators

Honey Bees
What are your bees doing?

Are they collecting pollen and tripping flowers?
or
Are they only collecting nectar and collecting pollen somewhere else?

Slide 11

What Seed Producers Can Do
- Lobby breeders to select for seed yield
- Lobby for comparative seed yield trials to be held in this district

Appendix 2
Letters to Participating Lucerne Growers

RE IPB/RIRDC Lucerne Project

1999

Dear

The field measurement and collection phase of this project for 1999 is now complete.

Thank you very much for permitting access to your fields, your informative discussions and ongoing support. I now have well over a thousand samples to analyse and interpret before moving to the next phase of the project which involves relating observations and performance of plants to management practices and seed yield.

In order to do this I would appreciate your cooperation in supplying me with the information requested on the attached spreadsheet related to timing of operations, specific land management practices and yields. I also attach a rough map indicating the fields and varieties. Would you check that I have the correct varieties in the fields please?

I am very happy with the way this project is progressing and am confident that it will achieve its aims to

- help seed producers recognise the most profitable varieties to grow,
- identify the best management strategies to increase seed yield, and
- demonstrate to breeders the need to select for increased seed yield as well as other characters when they develop new varieties.

When I have completed the analysis of the questionnaires and the sampling, I will organise an information session in your area to bring you up to date with my findings and to seek your input into the next phase of the project.

I look forward to your continuing co-operation.

Kind regards

Ross Downes
Research Director

IPB/RIRDC Lucerne Project 2001

Dear

Thank you very much for permitting access to your fields, your informative discussions and ongoing support with this RIRDC funded project to investigate the seed production of lucerne varieties. I am confident that the findings will be useful to lucerne seed producers both directly, and indirectly, through development of higher seed-yielding varieties in the future.

The field measurement and collection phase of the project finished when I took the final samples from crops in March. During the next few months I will complete the analysis of lucerne plants collected and prepare a report detailing the research findings and conclusions.

Samples collected in the 1998-99 season revealed considerable variation among varieties and between fields, reflecting the effects of timing, management, irrigation and soil characteristics. There was also a huge amount of variation within varieties, with some plants producing large quantities of seed and others little. These observations were continued during the following two crops 1999-00 and 2000-01 in which different conditions affected seed yield. All of these factors will be taken into account in interpreting findings.

I anticipate that the reasons for some varieties consistently producing high seed yields and others being less productive will be identified. This will assist breeders to focus more on seed production when new varieties are being developed and it will allow seed growers to evaluate seed production potential of varieties available for seed production contracts. As I suggested at field meetings, the appropriate contract price should reflect the seed yield potential of varieties. This can be easily determined if new varieties are compared and evaluated in seed production trials.

When variation in seed production was observed within fields in 1999 and it appeared that 25% of plants produced more than 50% of the seed, seed was harvested from both good and poor seed producing plants. When this was sown the following year it was found that good seed producers had progeny that were good seed producers and poor setters produced inferior descendents. This demonstrated that breeders should be able to improve seed production by selection.

During the 1999-2000 season particular attention was paid to frequency and activity of pollinating insects, particularly bees. There were mostly about 2 bees per square metre working in fields, but bees were very rarely observed to trip flowers – they were working the flowers for nectar without tripping and cross pollinating flowers. Nevertheless plants that were setting pods strongly had large numbers of tripped flowers. This indicated that n some plants flowers tripped automatically, without bees being involved. It was concluded that when a flower tripped a shower of pollen was released and this cross pollinated flowers on neighbouring plants

To investigate the possibility that plants were self-pollinating, which leads to weak progeny, seed was collected from white and cream flowered plants in various fields in 2000. When this seed was sown, the flower colour on the progeny was observed to be mostly blue, indicating that there was a good deal of cross-pollination. This provides evidence that automatic tripping, in the absence of bees tripping flowers, leads to cross-pollination.

It will help me interpret my observations if you could provide me with information on management and yield in your fields in 1999-2000 and 2000-01 on the attached spreadsheets. Also attached is a rough map indicating the fields and varieties. Would you please check that I have the correct varieties in the fields? I would very much appreciate your help with this.

I expect to produce the final report on this project by the end of September. I will send you a draft copy when it is ready and would very much appreciate your comments on this document.

Thank you again for your support and cooperation.

Kind regards

Ross Downes

Field Report

Grower		Date (Day and Month of)							Yield	Notes
Field	Variety	Last Cut	Irrigation 1	Irrigation 2	Irrigation 3	Irrigation 4	Irrigation 5	Harvest	kg/ha	

Appendix 3 Travel Grant Report

TA001-12

A Travel Report presented to RIRDC

A report on the
37th North American Alfalfa Improvement Conference,
Madison, Wisconsin, 16-19 July 2000.

by

Dr Ross Downes,
Innovative Plant Breeders
Principal Investigator,
RIRDC Project IPB-1A,
Evaluation of lucerne varieties for seed yield and strategies to enhance seed productivity

Summary

Attendance at the 37th North American Alfalfa Improvement Conference provided useful information and an extensive list of contacts which will be of great benefit to RIRDC Project IPB-1A, Evaluation of lucerne varieties for seed yield and strategies to enhance seed productivity.

Reports of the success of spring flowering and seed production are encouraging and suggest that the concept of early flowering should be evaluated in Australia. This information has since been presented to collaborating seed growers at locally held meetings and they are being encouraged to experiment with early and late flowering crops. Many seed growers set aside their crops for seed production in summer when high temperatures make watering expensive and inefficient and have deleterious effects on flower tripping and seed set.

Considerable research on seed production is being undertaken in France and discussions with French researchers were very useful. They have identified considerable variation within varieties for seed production, similar to that observed in Project IPB 1-A. In both countries it has been concluded that breeders have not seriously selected for seed yield. There is excellent reason to expect yield can be improved substantially in both countries.

In France native pollinators trip flowers, and in the US various bees are effective in diverse seed production regions. In Australia we need to examine how flowers are tripped, how pollen is moved from plant to plant, and determine the extent of inbreeding which tends to weaken lucerne plants. Resolution of these issues will help identify the appropriate breeding strategies for lucerne.

There are considerable efforts being undertaken to research the application of biotechnology to lucerne. Although lucerne can be modified relatively easily, few products are available for commercialisation, particularly because of legal issues and adverse consumer reactions.

Novel genetic resources are being used overseas in efforts to develop varieties of lucerne suitable for grazing. In Australia grazing tolerant varieties would have advantages in ease of management compared with traditional hay types which must be rotationally grazed.

Travel Report

Itinerary

Travel to Madison, Wisconsin

Arrive Madison 15 July 2000

Attend Conference 16 July to 19 July 2000

Return to Australia

Purpose

It was anticipated that attendance at this conference would meet the following objectives:

Identify recent international research findings of potential benefit to Australian lucerne hay and seed producers

Consider environmental factors affecting seed production with a variety of people involved in seed production research

Discuss with breeders the implications of cross-pollination and self-pollination on plant vigour and production

Determine the current thinking worldwide on the significance and effectiveness of pollinating insects

Develop contacts working in complementary disciplines with whom findings might be discussed

Achievements/ Findings

There is considerable emphasis on biotechnological approaches to lucerne improvement. Basic studies reporting transformation mechanisms were reported as well as more applied issues. At a biotechnology symposium the point was made that although it is relatively easy to transform lucerne, few products are ready for commercialisation. In part this is due to complex legal issues concerning patents, but also delays can also be attributed to community concern about the use of genetically modified (GM) products, even as animal feed. Current indications are that among the first GM products to be commercialised will be both winter active and winter dormant round-up ready (resistant) lucerne varieties. These are expected to help substantially in weed control. Efforts to produce lucerne which does not cause bloat in cattle, through incorporation of tannin genes, is proving difficult. The genes are expressed in the seed coat but not in the leaves where tannin is required.

Increased use of lucerne for grazing is being proposed in both the US and Europe. To improve the suitability of lucerne for grazing, selection of grazing tolerant varieties is proceeding. Varieties tolerant of cattle grazing have been produced in the US, particularly for growth with grasses which help balance the diet, minimising the bloat risk. Diverse germplasm is being evaluated in Europe in an effort to locate new sources of grazing tolerance. Creeping rooted types are being evaluated for grazing resistance but the inheritance of this character is complex, making it difficult to use.

Experiments were reported in which fodder production of ‘experimental’ lines was compared with production from the commercial varieties produced from them. It was concluded that yield of many ‘experimental’ varieties was not a good indicator of yield of varieties derived from them. The implication was that yield data obtained during variety testing, though widely used, can be misleading. This casts doubt on the effectiveness of evaluation procedures in many breeding programs.

Diseases and pests of lucerne vary in different countries and through quarantine, efforts are made to prevent their spread. A number of papers reported progress in developing varieties with resistance to various pests and diseases. In the US varieties have now been bred with resistance to the potato leafhopper. Delegates were able to view research and trials of pest resistant varieties on two research stations on a field trip during the conference. Presumably appropriate varieties will be available for use in Australia should this pest be introduced.

Lucerne seed production was discussed in both papers and posters. Tahiraj *et al* reported that in Albania early May is the most desirable time to cut the crop for subsequent seed production. This timing has also been recommended in various studies reported in Canada in the past. This is much earlier (equivalent to early November in Australia) than is the practice in Australia except in dry land crops .

Seed yield is being studied extensively in France and progress was reported in several posters presented at the conference. On several occasions seed production issues were discussed with French delegates. Huyghe *et al* studied the effect of cultivar and environment on seed yield by evaluating 12 varieties in 12 environments (4 locations for 3 years). They reported a high correlation between seed yield and harvest index and interpreted this to mean that selection for high seed production should not be deleterious for vegetative growth and forage production. This is not a strictly appropriate interpretation as fodder yield is determined by cutting at the beginning of flowering, whereas seed yield depends on factors at flowering and subsequently. An alternative interpretation of the results is that as plants with the highest harvest index are the highest seed producers, increased seed production can be obtained by selection for either seed yield or harvest index. Certainly plants with high harvest index (seed yield in relation to total above ground production) are more efficient in use of resources.

In another paper Huyghe *et al* reported a trial in which 2 varieties were studied in each of 27 environments. In this case seed yield was related to above-ground dry matter production. They proposed that the relationship between seed yield and biomass be used as a diagnostic tool in investigating limiting factors in seed production in lucerne. In another study to determine the distribution of seed in the lucerne crop canopy Huyghe *et al* found that few stems had more than 11 main stem inflorescences. These findings agree with observations on those plants producing high seed yield in Australia. However it is a much lower figure than on the many plants which have larger numbers of inflorescences. This difference may be attributed to the effectiveness of large numbers of native pollinating insects in France compared with the lack of effective pollinators in Australia. They also found that there was more seed on inflorescences deep in the crop canopy and that seed production is lower at the top of the plant. This contrasts with observations in Australia where seed production commonly varies along the stem with lower inflorescences particularly producing little seed which encourages the plant to continue flowering until more seed is set.

French researchers also provided copies of recent papers from scientists in France not attending the conference. In one of these, Bolanos-Aguilar *et al* (2000) reported on the genetic variation for seed yield in lucerne. They examined varieties from many countries and observed much greater variation within varieties than among varieties. This is in agreement with observations in RIRDC Project IPB-1A that 25% of plants produce 50% of the seed, with the remainder of the plants producing little seed. In another paper Huyghe *et al* reported on opportunities to select for seed weight per inflorescence to increase seed yield. They concluded that this could be achieved through traditional methods of breeding. They also noted that though seed yield is important in the commercial uptake of varieties, little progress in improvement of seed yield has been achieved in recent times. They attributed this to the fact that seed yield is considered late in breeding cycles and appropriate selection criteria have not been identified.

Historically many US scientists have considered the possibilities of producing high yielding hybrid varieties of lucerne. One aspect of this was reported in a paper which explored the combining ability of *Medicago sativa* and *M. falcata*. There was also an opportunity to discuss implications of inbreeding, a consideration in hybrid development, with Dr Ted Bingham formally from Cornell, who has reported vigorous plants within inbred populations through an accumulation of superior genes as inferior plants are eliminated. His findings are encouraging should it emerge that Australian varieties experience a degree of inbreeding because of a lack of effective pollinators. The level of inbreeding in Australian varieties is being investigated in RIRDC Project IPB-1A.

US delegates to the conference did not address seed production issues. There are several reasons for this. On the one hand, the various seed production regions in North America have appropriate pollinators - leaf-cutter bees, bumble bees, alkali bees and honey bees which appear to effectively pollinate the crop and assure acceptable seed yields in particular zones. Resistance to pests is regarded as more important than increased seed production and chemicals, insecticides and fungicides are used to overcome problems until resistant varieties are available. Biotechnology and related basic studies are currently absorbing much of the lucerne research effort.

Benefits

Attendance the conference provided the following benefits:

Facilitation of discussions with scientists researching inbreeding, genetic resources and seed production, and provided opportunities to maintain on-going contact with those active in this area.

Recognition of the fact that Australian lucerne seed producers often harvest high yielding crops without the benefit of the efficient pollinating insects available in other countries. This emphasises the potential importance of RIRDC Project IPB-1A to clarify the factors affecting lucerne seed production in Australia.

Realisation that the huge variation in ability to set seed in Australian lucerne varieties is observed in a wide range of varieties evaluated in France also. This appears to reflect a lack of awareness of the value of high seed yield by those breeding lucerne varieties world wide.

Discovery of renewed international interest in the development of grazing-tolerant varieties. This suggests that there are opportunities for Australian breeders to enhance the grazing tolerance of varieties for local use and for seed export.

Identification of biotechnology as a significant area of increasing research effort.

Acceptance that progress in biotechnology is restrained by legal issues, patents and a lack of community acceptance of genetically modified products.

Recommendations

Breeders of lucerne, grasses and other open pollinated crops should be encouraged to select for seed production as well as fodder yield.

Australian breeders should be alerted to the possibilities of using the wide germplasm resources available to breed grazing-tolerant lucerne varieties as well as hay types.

Legal problems, non-tariff trade barriers and lack of current consumer acceptance should be taken in to account when additional support for biotechnology is being considered.

Suggested Dissemination of Information

Information gathered at this conference is being taken into account in planning the next phases of RIRDC Project IPB-1A.

Relevant findings will be incorporated in the final report.

Information from the conference has been presented to seedgrowers at district meetings and suggestions made about modification of practices.

Comments

Attendance at this conference was most valuable in providing opportunities for comparison of factors affecting lucerne seed production in Australia with those being experienced overseas. Variation within varieties provides Australian and overseas breeders with considerable opportunities to increase seed yield through selection. However in France, Canada and the US efficient pollinators are available naturally or through efficient commercial pollen vectors. There are still problems in Australia ensuring adequate tripping of flowers and seed set through action of pollinating insects.

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References

Anderson, D. 2001. personal communication.

Armstrong, J.M., and W.J. White. 1935. J. Agr. Sc. 25: 161-79.

Bohart, G.E. 1957. Ann. Rev. Ento. 2: 355-80

Bolanos-Aguilar, E.D.,C. Huyghe, B. Julier, and C. Ecalle. 2000. Agronomie 20: 333-45.

Bolton, J.L. 1948. Sci. Agric. 28: 97-126.

Bolton, J.L., and J.R. Fryer. 1937. Sci. Agr. 18: 148-60.

Boren, R.B., R.L. Parker, and E.L. Sorensen. (1962). Crop Sci. 2: 185-8.

Bradner, N.R., and R.V. Frakes. 1964. Crop Sci. 4: 111.

Bula, R.J., and M.A. Massengale. 1972. Agron. Monogr. 15. ASA. Madison, WI.167-84.

Burkart, A. 1937. Herb. Abst. 7: 296-7.

Busbice, T.H., and C.P. Wilsie. 1966. Crop Sci. 6: 377-8.

Carlson, J.W. 1946. J. Amer. Soc. Agron. 38: 502-14.

Clarke, A.E., and J.R. Fryer. 1930. Sci. Agr. 11: 38-43.

Cooper, D.C., R.A. Brink, and H.R. Albrecht. 1937. Amer. J. Bot. 24: 203-13.

De Barro, J. 2001. RIRDC. Pasture Seeds 01/79. 11.

Doull, K.M. 1961. J. Aust. Inst. Agric. Sci. 27: 11-5.

Doull, K.M. 1967. in The Lucerne Crop. Ed Langer, R.H.M. Reed Wellington.

Dwyer, R.E. 1931. Agric. Gaz. N.S.W. 42: 703-8.

Dwyer, R.E. and S.L. Allman. 1932. Agric. Gaz. N.S.W. 43: 141-6.

Dwyer, R.E. and S.L. Allman. 1933. Agric. Gaz. N.S.W. 44: 363-71.

Engelbert, V. 1932. Sci. Agr. 12: 593-602.

Fryer, J.R. 1939. Sci. Agr. 20: 131-9.

Grandfield, C.O. 1945. J. Agr. Res. 70: 123-32.

Hadfield, J.W. and R.A. Calder. 1936. N.Z. J. Sci. & Tech. 17: 577-95.

Hanson, C.H. (1972). Agron. Monogr. 15. ASA. Madison, WI.

Hare, Q.A., and G.H. Vansell. 1946. J. Amer. Soc. Agron. 38: 462-9.

Heinrichs, D.H. 1965. Canadian. J. Plant Sci. 45: 177-83.

Hely, F.W., and M. Zorin. 1977. Aust. J. Agric. Res. 28: 1015-27.

Hobbs, G A., and C.E.Lilly. 1955. Canadian J. Agric. Sci. 35: 422-32.

Humphries, A.W., and G.C. Auricht. 2001. Aust. J. Agric. Res. 52: 153-69.

Huyghe, C., E.D. Bolanos-Aguilar, C. Ecalle, J. Hacquet, and B. Julier. 1999. Proc. XIII Eucarpia *Medicago* spp.Group Meeting, Perugia.

Irwin, J.A.G., D.L.Lloyd, and K.F. Lowe. 2001. Aust. J. Agric. Res. 52: 699-712.

Jones, L.G., and C.R. Pomeroy. 1962. Calif. Agric. 16: 8-10.

Kauffeld, N.M., E.L. Sorensen, and R.H. Painter. 1967. J. Econ. Ento. 60: 1135-39.

Kauffeld, N.M., E.L. Sorensen, and R.H. Painter. 1969. Crop Sci.9: 225-8.

Kehr, W.R. 1973. Crop Sci.13: 296-8.

Kehr, W.R., and W.E. LaBerge 1966. Crop Sci. 6: 91-2.

Kimbeng, C.A. and E.T. Bingham, 1998. Aust. J. Exp. Agric. 38: 831-6.

Kirk, L.E. 1927. Sci. Agric. 8: 1-40.3

Kirk, L.E. 1933. American Naturalist 67: 515-31.

Kirk, L.E. and W.J. White. 1933. Sci. Agr. 13: 591-3.
Knapp, E.E. and L.R. Teuber. 1990. Crop Sci. 30: 270-5.
Knapp, E.E. and L.R. Teuber. 1993. Crop Sci. 33: 1181-5.
Knapp, E.E. and L.R. Teuber. 1994. Crop Sci. 34: 323-6.
Knapp, E.E., L.R. Teuber and J.A. Henning. 1993. Crop Sci. 33: 1176-80.
Knowles, R.P. 1943. Sci. Agric. 24: 29-50.
Kreitner, G.L., and E.L. Sorensen. 1985. Crop Sci. 25: 631-4.
Larkin, R.A., and H.O. Graumann. 1954. Bot. Gaz. 116: 40-52.
Lesins, K., E. Akerberg and Z. Bojtos. 1954. Acta Agric. Scand. 4: 239-56.
Maelzer, D.A., and D. Oliver. 1987. Annual Report, Waite Inst. 86/87: 125.
Maelzer, D.A., D.E. Pinnock, Annual Report, Waite Inst. 82/83: 127.
Maelzer, D.A., D.E. Pinnock, P.T. Bailey, and P.E. Madge. Annual Report, Waite Inst. 80/81: 121.
Palmer-Jones, T., and I.W. Forster. 1972. N.Z. J. Agric. Res. 15: 186-93.
Pankiw, P., and J.L. Bolton. 1965. Canadian J. Plant Sci. 45: 333-42.
Pankiw, P., J.L. Bolton, H.A. McMahon, and J.R. Foster. 1956. Canadian J. Agric. Sci. 36: 114-9.
Petersen, M.W. 1967.Crop Sci. 7:59-62.
Petersen, M.W. 1968 Crop Sci. 8: 263-4.
Petersen, M.W., G.E. Bohart, V.L. Marble, and E.C.Klostermeyer. 1972. Agron. Monogr. 15. ASA. Madison, WI. 689-720.
Pharis, R.L., and J. Unrau. 1953. Canadian J. Agric. Sci. 33: 74-83.
Reinhardt, J.F. 1952. Amer. Nat. 86: 257-75.
Rincker, C.M., V.L. Marble, D.E. Brown, and C.A. Johansen. 1988. Agron. Monogr. 29. ASA Madison, WI.
Sayers, E.R and R.P. Murphy. 1966. Crop Sci. 6: 365-8.
Sexsmith, J.J. and J.R. Fryer. 1943. Sci. Agric. 24:95-100.
Spafford, W.J. 1938. Dept. Agric. South Aust. Bull. 246.
Stephen, W.P. 1955. J. Econ. Ento. 48: 543-8.
Stevenson, T.M., and J.L. Bolton. 1947. Emp. J. Exp. Agr. 15: 82-8.
Tysdal, H.M., 1940. J. Amer. Soc. Agron. 32: 570-85.
Tysdal, H.M., 1946. J. Amer. Soc. Agron. 38: 515-35.
Tysdal H.M., and I. Clark. 1934. J. Amer. Soc. Agron. 26: 773-80.
Tysdal, H.M., T.A. Kiesselbach, and H.L. Westover. 1942. Negr. Agr. Exp. Sta. Res. Bull. 124.
Vansell, G.H., and F.E. Todd. 1946. J. Amer. Soc. Agron. 38: 470-88.
Viands, D.R., P. Sun, and D.K. Barnes. 1988. Agron. Monograph 29: 931-60.
Waldron, L.R. 1919. J. Amer. Soc. Agron. 11: 259-66.
Walker, R.B., E.G. Elliott and I.M. Smith. 1996. RIRDC final report DAN 75A. 30pp.
Woodward, D. and D.A. Maelzer. 1990. Annual Report, Waite Inst. 88/89: 129.